GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

THE SOUTH OF SCOTLAND

(SECOND EDITION, REVISED)

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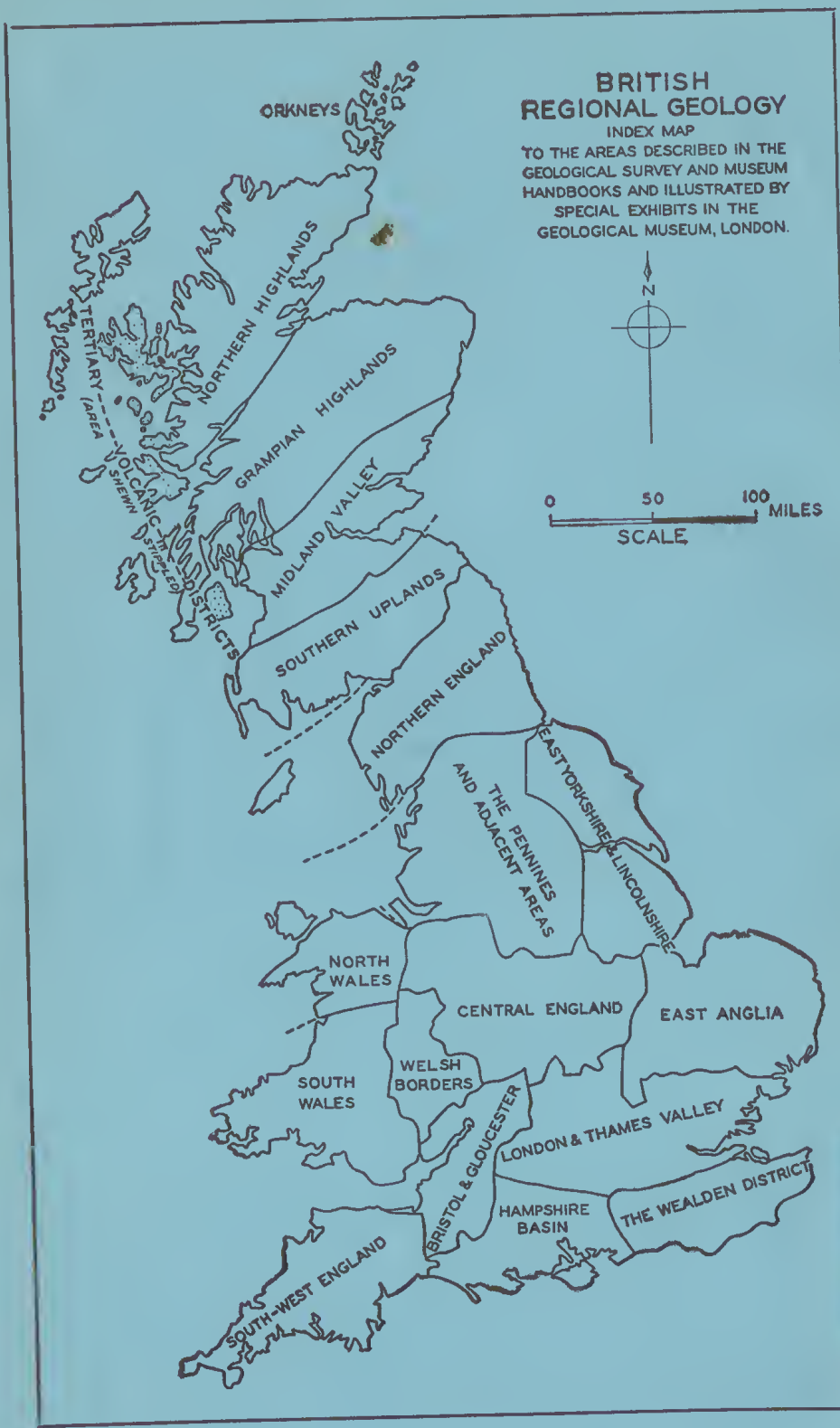
BRITISH
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INDEX MAP
TO THE AREAS DESCRIBED IN THE GEOLOGICAL SURVEY AND MUSEUM HANDBOOKS AND ILLUSTRATED BY SPECIAL EXHIBITS IN THE GEOLOGICAL MUSEUM, LONDON.
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TERTIARY VOLCANIC AREA
MIDLAND VALLEY
SOUTHERN UPLANDS
NORTHERN ENGLAND
THE PENNINES AND ADJACENT AREAS
EAST YORKSHIRE & LINCOLNSHIRE
NORTH WALES
CENTRAL ENGLAND
EAST ANGLIA
SOUTH WALES
WELSH BORDERS
BRISTOL & GLOUCESTER
LONDON & THAMES VALLEY
HAMPSHIRE BASIN
THE WEALDEN DISTRICT
SOUTH-WEST ENGLAND

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

GEOLOGICAL SURVEY AND MUSEUM

BRITISH REGIONAL GEOLOGY

The South of Scotland

(SECOND EDITION, REVISED)

By
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CONTENTS

ILLUSTRATIONS

FIGURES IN TEXT

PLATES

THE SOUTH OF SCOTLAND

I. INTRODUCTION

TOPOGRAPHICALLY, SCOTLAND MAY be divided into three distinct regions, the Highlands, the Midland Valley and the Southern Uplands. To the last mentioned the term South of Scotland is generally applied. The region is bounded on the north by the faulted southern margin of the Midland Valley, and on the south by the Solway Firth and the Cheviot Hills. Politically, a small part of the area, including Berwick, is included in England.

Between these boundaries the Uplands stretch as an almost continuous belt of high ground from the North Sea to the Irish Channel. To the north-east the Lammermuir Hills rise sharply above the plain of East Lothian to heights varying from 1,500-1,700 ft., but southwards they fall gently towards the low-lying area known as the Merse of Berwickshire. Westwards, the Moorfoot Hills overlook the Midlothian coal-basin, and attain even greater heights than those of the Lammermuirs; still farther to the south-west, particularly in the district between Peebles and Moffat, many of the hill-tops are over 2,600 ft. high, Broad Law reaching the height of 2,754 ft. Between the rivers Clyde and Nith are the Lowther Hills, the highest point being Green Lowther, the summit of which is 2,400 ft. Beyond the Nith the most prominent eminences are those formed by the granite masses of Cairnsmore of Fleet, Cairnsmore of Carsphairn and Criffel, the latter rising with a steep slope from the Solway. More prominent still are the rugged hills of Merrick and Kells consisting mainly of altered sediments which surround the Loch Dee mass of granite in the Loch Doon country.

There are two distinct types of scenery in the Uplands. North-east of the river Nith and ranging almost to the Berwickshire coast, the hills rise as smooth, rounded eminences covered with grass or heather, and in the central portion they display the features characteristic of an elevated table-land traversed by deep and narrow valleys. Of the latter that of the Moffat Water is typical. To the south-west of the Nith, however, the scenery takes on a different aspect as a result of the presence of large intrusions of granite; the smooth, rounded, somewhat monotonous type giving place to one of wild and rugged grandeur. In the Border country, especially in Liddesdale and the upper reaches of the Teviot, there is a mingling of moorland and cultivated valleys; and here, as well as in the lower parts of the Vale of Tweed, picturesque isolated hills formed either of volcanic necks, intrusive or extrusive masses of lava, add a peculiar charm to the scenery. Among these perhaps the most attractive are the Dirrington Laws near Duns, the Black Hill of Earlston, the triple peaks of the Eildons overlooking Melrose (Pl. IIA), Ruberslaw in Teviotdale and the numerous striking eminences that diversify the hill country between the Liddel and the higher reaches of the Teviot.

Drainage. The principal watershed is that which separates the rivers flowing southwards from those running north-westwards and eastwards. The largest river draining the Uplands is the Tweed, which flows in an easterly direction to the North Sea. Among its principal tributaries are the Lyne, Ettrick, Gala, Teviot and Whiteadder, but of these the Lyne is perhaps the most interesting. This stream rises in the Pentland Hills in the Midland Valley, and after crossing the low-lying area occupied by the Old Red Sandstone at West Linton, it enters the Uplands and later joins the Tweed west of Peebles.

The streams draining into the Firth of Clyde are the Clyde, Doon, Girvan and Stinchar, while those flowing southwards to the Solway are the Nith, Dee, Fleet, Cree and the smaller stream of the Luce. The Esk, after receiving the Liddel Water, also empties its waters into the Solway south of Gretna. In this drainage system the Nith presents the most distinctive feature; it rises on the northern slope of the Uplands and flows northwards to the low ground occupied by Carboniferous rocks over which it runs in an easterly direction to New Cumnock; thence turning southwards it travels across the Uplands to the Solway Firth.

The initiation of the main features of the present drainage system is of a geologically recent date. Volcanic dykes of Tertiary age cross hill and valley and traverse all the ' solid ' formations irrespective of stratigraphical position; in these circumstances, therefore, it is clear that the valleys have been eroded subsequent to the date of the intrusions. Indeed, it is probable that the South of Scotland was wholly or partially covered by Mesozoic and Tertiary deposits, and it was on a floor composed of these younger rocks that the drainage was initiated. The disposition of the streams was thus originally independent of the structure of the Palaeozoic platform. The earliest or consequent rivers appear to have had their sources far to the north of the Uplands, and to have flowed in a south or south-easterly direction. Later, as the denudation of the cover progressed, these transverse rivers were intercepted by the establishment of a subsequent or longitudinal system of drainage; the river Lyne provides an excellent example of a consequent stream which has been captured by a subsequent, in this instance, the river Tweed. In a similar manner the Solway-Liddel subsequent has deflected the old consequent rivers of the Nith, the Ken-Dee and the Cree. On the other hand, the anomalous behaviour of the river Nith near New Cumnock is clearly the result of the deflection of an easterly flowing subsequent stream having its source on the northern slope of the Southern Uplands; it has been captured by the consequent Nith, after the latter river had been beheaded by the extensive denudation of the Midland Valley.

Evidence of a much earlier drainage system, however, has been revealed by the extensive denudation which the region has undergone. These are transverse valleys filled with Palaeozoic deposits of later age than the Silurian. In Lauderdale, one of these hollows which traversed the Uplands during the Old Red Sandstone period was filled up with coarse sediments of Upper Old Red Sandstone age. A similar infilled valley lies between Greenlaw and Dunbar. It is possible that Gala Water, though now free of Old Red Sandstone deposits, also runs along the site of one of these ancient hollows.

In the south-west other valleys filled with Carboniferous and Permian deposits strike into the heart of the Uplands. These depressions are perhaps of tectonic origin. In Annandale a deep hollow occupied by Permian breccias and sandstones runs almost continuously from near Lockerbie northwards to the Devil's Beef Tub, five miles north of Moffat. There are no traces of Carboniferous rocks in the narrower part of the infilled valley, but it is possible that they may underlie the broad outcrop of Permian sandstones north-west of Lockerbie. In Nithsdale an important hollow appears to have run across the Southern Uplands from the Solway Firth by way of Dumfries and Thornhill northwards to Durisdeer, and perhaps as far as the Snar Valley, which lies close to the boundary-fault. A branch of this hollow seems to have extended to Sanquhar. The deposits, which were laid down in this depression, are now confined to four separate areas, Dumfries, Thornhill, Sanquhar and the valley of the Snar. The Thornhill and Sanquhar basins are occupied by Lower and Upper Carboniferous and Permian rocks, but only the latter formation is represented in the Snar Valley. In the Dumfries basin also Permian rocks only are known, but the occurrence of Carboniferous strata is probable. Both formations, however, are present in the Loch Ryan hollow, and this infilled valley was perhaps connected with the Ballantrae basin in which Permian rocks only occur.

It is likely that all these hollows were originally connected with a deep depression (*see* p. 51) running in a north-easterly direction from the Solway Firth to the Merse of Berwickshire, in which Upper Old Red Sandstone and Carboniferous sediments were deposited, and it is of interest to note that similar infilled hollows running northwards towards the depression have been traced to the Cheviot Hills.

Geological Research. The problems of the Southern Uplands have long attracted the attention of geologists, and the region has played an important rôle in the history of geological research. Towards the close of the eighteenth century, Hutton, one of the founders of the science, was led to formulate important theories regarding the origin and physical history of the Palaeozoic rocks as a result of his studies of the sections exposed in the banks of the river Jed, near Jedburgh, and in the cliffs at Siccar Point on the Berwickshire coast (Pl. 1). His views were embodied in the *Theory of the Earth*, published in 1795 and are now regarded as fundamental principles of geology. At the same time, Hutton's friend and co-worker, Sir James Hall, in an endeavour to explain the cause of the remarkable folding of the oldest rocks of the region, devised a machine to demonstrate that similar convolutions could be produced in beds of clay. By experimental methods he showed that strata, originally flat, were folded as a result of powerful forces acting in opposite directions. He also proved that similar structures were produced by the intrusion of granite, which he argued was later in time than the surrounding rocks, and had flowed into its present position from below upwards in a liquid state.

It was in the Uplands, too, that Lapworth began his brilliant stratigraphical and palaeontological studies and, by his application of the principles of William Smith, he demonstrated the value of graptolites as aids in working out the order of succession in the complicated structure of a highly folded region. In a series of important papers he showed a masterly

grip of the problems of the Southern Uplands, and paved the way for the monumental volume on the Silurian Rocks by Peach and Horne, issued by the Geological Survey.

In the following account of the Ordovician and Silurian rocks, the writer has drawn freely on these publications, and has supplemented it by his own observations. The lists of fossils throughout the text have been compiled from the Geological Survey collections and the well-known collection made by Mrs. R. Gray of Girvan.[1]

Geological Formations. The following formations or rock groups are represented in the South of Scotland:

Recent and Pleistocene		Soils, blown-sand, peat, river and lake alluvia Raised-beach deposits Glacial sand, gravel, moraines and boulder-clay
Tertiary		Many volcanic dykes
Triassic		Annan Red Sandstone and Marls
Permian		Dumfries Sandstone, red sandstones and breccias; lavas and agglomerate
Carboniferous		Barren Red Measures; red sandstones and shales
		Productive Coal Measures; coals, shales, fireclays and sandstones
		'Millstone Grit'; sandstones and grits
	Carboniferous Limestone Series	Upper Limestone Group Kilnholm Coal Group Lower Limestone Group
	Calciferous Sandstone Series	Lawston Linn and Lewis Burn Coals Glencartholm Volcanic Group Fell Sandstone Group Cementstone Group Whita Sandstone Birrenswark and Kelso Lavas, etc.
Old Red Sandstone		Upper Old Red Sandstone; breccias, sandstones, marls and cornstones
		Lower Old Red Sandstone; conglomerates, sandstones, lavas and granitic intrusions
Silurian		Wenlock; greywackes, conglomerates, shales, etc.
		Llandovery; Gala Group: greywackes, conglomerates, shales and Birkhill Shales in Central Belt. Conglomerates, sandstones, limestones, etc., in Girvan area
Ordovician	Ashgill and Caradoc[2]	Hartfell Shales in Central Belt; conglomerates, greywackes, shales, limestones and lavas, etc., in Northern Belt; conglomerates, shales, limestones, etc., in Girvan area
		Glenkiln Shales in Central Belt and greywackes and shales in Northern Belt; conglomerates, shales, cherts, etc., in Girvan area
	Arenig	Shales cherts, lavas, tuffs and agglomerates in Central and Northern Belts and in Girvan area

Structure. The greater part of the Southern Uplands is occupied by highly folded Ordovician and Silurian rocks (Figs. 1-3). Although the principal folding of the region took place at the close of Silurian time an important tectonic movement occurred after the deposition of the Arenig. The current view maintains that the Arenig lavas and associated sediments were invaded by masses of serpentine and other plutonic rocks, and that the whole assemblage was afterwards folded, upheaved and denuded before Glenkiln time. The writer, however, is of the opinion that several of the so-called intrusions are rocks of Pre-Cambrian age, and had originally formed part of the floor on which the Arenig strata were laid down; and

[1] The graptolite names in this edition have been revised by Dr. G. L. Elles.
[2] *See* remarks on p. 16.

that during these pre-Glenkiln movements the younger rocks were pressed into a series of sharp folds above the more rigid platform, much in the way a table-cover becomes pleated when pushed along a table between two opposing forces. In other words, the original peneplane was converted into a plane of décollement.

At the close of Silurian time, however, the region was again subjected to intense lateral pressure, and, as a result, the Ordovician and Silurian rocks were squeezed into two primary folds, each of which is composed of a series of parallel flexures. As was first demonstrated by Lapworth, the axial lines of the two folds run in a north-east to south-west, or Caledonian, direction throughout the region from the North Sea to the Irish Channel. The northern line starts at Dunbar and passes through the Lammermuir and Moorfoot Hills by the Leadhills and the Loch Dee granite to the sea at Portpatrick. Along this line the axial planes of the parallel flexures dip inwards on the north-west and south-east sides towards a central vertical axis, thus producing a fan-shaped or pseudo-synclinal arrangement of the beds. The southern line commences at St. Abb's Head and extends by way of Hawick and Dumfries to the Mull of Galloway, and from this central vertical axis the axial planes of the parallel folds slope away on opposite sides, and thus form an inverted fan-structure or pseudo-anticlinal. This disposition of the rocks between Hawick and Dumfries deceived the early investigators of the region, who regarded the structure as that of a simple anticlinal fold; it was not until Lapworth discovered the true order of succession of strata that the highly complicated folding of the region was understood. In many respects the tectonic structure of the Southern Uplands resembles that of the Jura mountains.

The results of this folding are somewhat paradoxical, an apparent simplicity of disposition masking great complexity of structure. Following the pre-Old Red Sandstone denudation of the region, all the Llandovery and Wenlock rocks were removed from the pseudo-synclinal tract of the Leadhills, while in the pseudo-anticlinal area between St. Abb's Head and the Mull of Galloway, Llandovery strata are completely represented and pass beneath the Wenlock greywackes. The rocks of the Southern Uplands, therefore, form three distinct belts: a Northern Belt occupied by highly folded Arenig, Glenkiln and Hartfell rocks; a broad Central Belt mainly composed of similarly flexured Llandovery greywackes and shales in which the Ordovician strata occur along the axes of complex anticlinal folds as long, narrow, boat-shaped inliers; and a Southern Belt solely occupied by isoclinally folded Wenlock rocks (*see* Map). In effect, the general disposition of the highly folded formations as shown on a geological map is similar to that presented by a series of gently inclined beds.

Lying beyond the boundary fault in Glen App is a fourth area, which comprises the country between Ballantrae and Girvan, and extends inland as an inlier on the north side of the Girvan valley to Blair and Straiton. This region includes a varied assemblage of rocks ranging in age from the Arenig up to the Carboniferous.

A further result of the great lateral pressure exerted on the strata of the Uplands during the folding of the region is shown by the schistose and cleaved character of the rocks of certain areas. These secondary structures are restricted to narrow zones where the strain had been most intense. Thus,

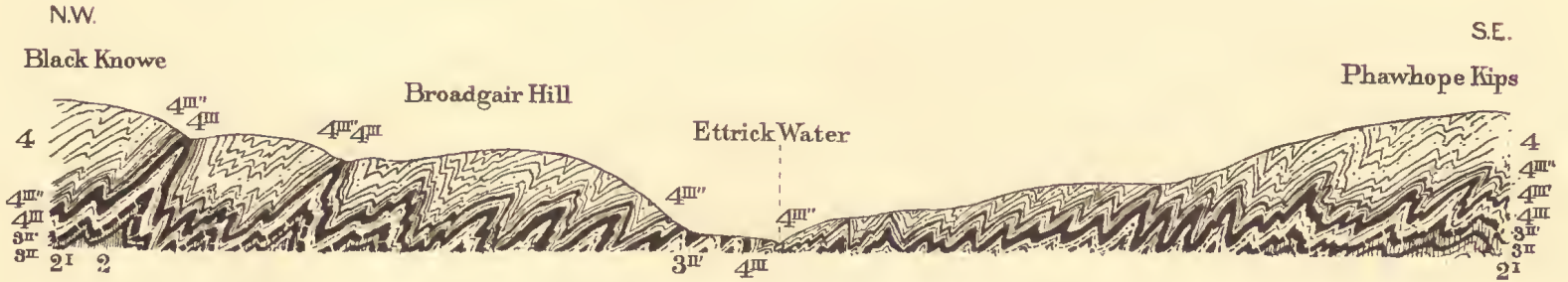

FIG. 1. *Generalized section from Black Knowe, across Ettrick Water to Phawhope Kips.* (Length, two miles.)

2, Glenkiln Chert; 2^{1}, Glenkiln Shales; 3^{11}, Lower Hartfell Shales; $3^{11'}$, Barren Mudstones; 4^{111}, Lower Birkhill Shales; $4^{111'}$, Upper Birkhill Shales; $4^{111''}$, *R. maximus* Zone; **4**, Gala Group.

This section through part of the Central Belt illustrates the manner in which the rocks are folded into isoclines, the axes of which dip towards the north-west.

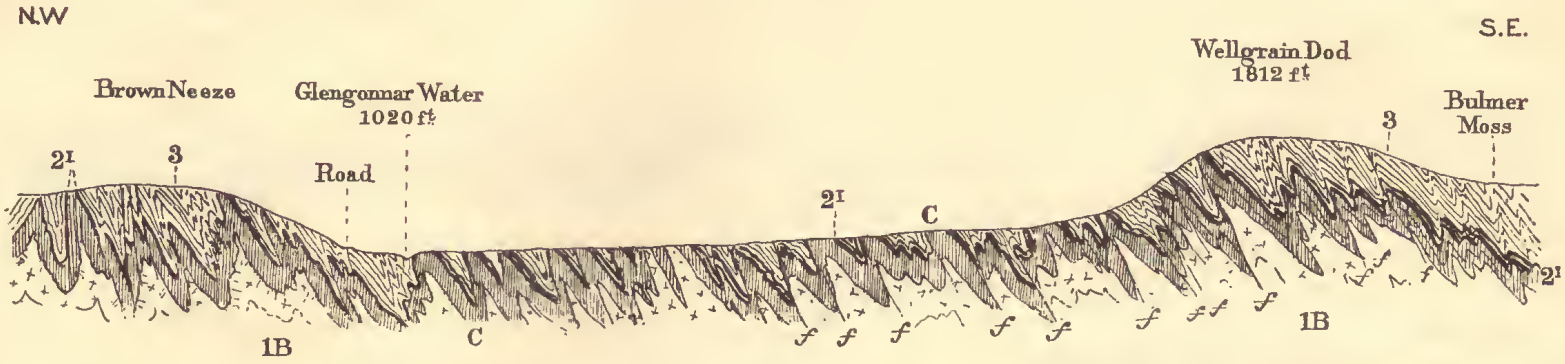

FIG. 2. *Section exposed in the Clowgill Burn, Glengonnar Water, Lanarkshire.* (Length, a mile and a quarter.)

1B, Arenig volcanic rocks; **C**, Radiolarian chert; **2¹**, Glenkiln Shales; **3**, Lower Hartfell Shales; **f**, Fault.

In this section through part of the Northern Belt the axes of the isoclines are inclined towards the south-east, a direction opposite to that shown on Fig. 1.

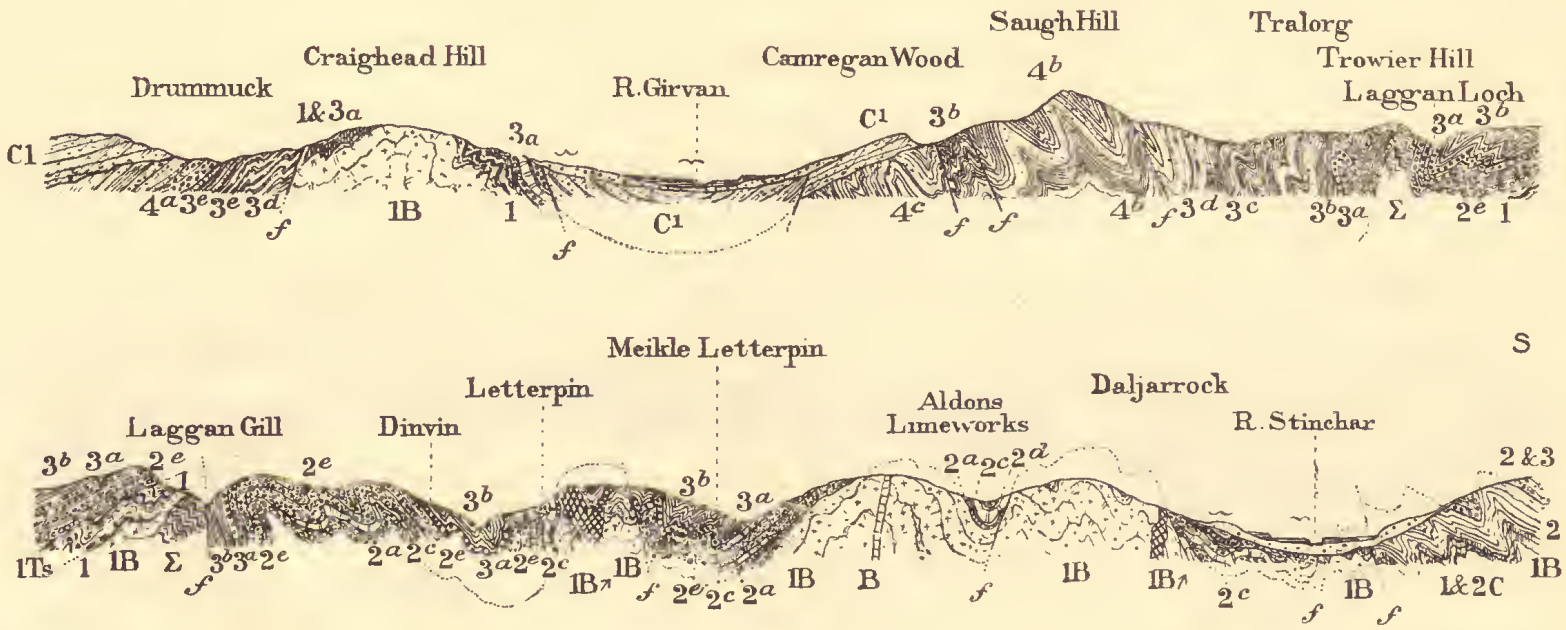

FIG. 3. *Generalized section across the Girvan Area from Drummuck to River Stinchar, near Daljarrock.* (Length, eleven miles.)

1B, Arenig lava; **1Ts**, Arenig agglomerate; **1**, Arenig black shales; Σ, Serpentine; **1B↑**, Intrusive basic rocks; **2** and **3C**, Radiolarian chert; **2**, 'Tappins Beds'; **2** and **3**, Caradoc and Ashgill; **2a**, Kirkland Conglomerate; **2c**, Stinchar Limestone; **2e**, Benan Conglomerate; **3a**, Balclatchie Group; **3b**, Ardwell Group; **3c**, Whitehouse Group; **3d**, Barren Flagstone Group; **3e**, Drummuck Group; **4**, Silurian; **4a** Mulloch Hill Group; **4b**, Saugh Hill Group; **4c**, Camregan Group; **C1**, Lower Old Red Sandstone; **B**, Dolerite Dyke; **f**, Faults; ⌣⌣, Boulder clay; ⌒⌒, Alluvium.

schistose rocks are found in places along the southern edge of the pseudo-synclinal area of the Leadhills, while on the northern and southern sides of the pseudo-anticlinal belt the strata are locally highly cleaved.

In the Ballantrae district the serpentine and other rocks, regarded as intrusions of post-Arenig age, have in places undergone great deformation, resulting in the production of highly sheared rocks, and the conversion of certain masses of epidiorite into hornblende-schist. Since this marked dynamic metamorphism does not affect the adjacent Arenig strata, however, it has been suggested by the writer that these movements are of pre-Arenig age.

The succeeding formations, Old Red Sandstone, Carboniferous, Permian and Triassic, occupy a small part of the region. They are represented by relatively horizontal or gently inclined beds of rock, and where each formation has come to rest on the highly folded Ordovician and Silurian strata the junction is one of strong unconformity. The low inclination of the bedding-planes, however, does not imply that the formations have not been involved in later movements. Vertical oscillations of the region have been followed by repeated emergence or submergence, and these interruptions of sedimentation are clearly indicated by numerous intra-formational disconformities.

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II. ORDOVICIAN

Arenig

THE OLDEST FOSSILIFEROUS rocks in the Southern Uplands are of Arenig age. These are black shales and variously coloured cherts interbedded with coarse agglomerates associated with beds of tuff; in the lower part are flows of spilitic lavas poured out of submarine volcanoes. The spilites attain their finest development in the neighbourhood of Ballantrae in Ayrshire, and in the south-western part of the Northern Belt. The natural base of the formation has not been recognized, but it appears probable to the writer that the Arenig rocks were laid down on a floor of Pre-Cambrian strata. In the central region the formation is represented by radiolarian cherts, grey shales and fine volcanic ash, exposed only in the cores of the deepest anticlines, and probably corresponding to the highest beds in the section below. In the Southern Belt Arenig rocks are not exposed.

Near Ballantrae the section at Bennane Head may be taken as showing the general succession, which in descending order is as follows:

	FT.
Red, green and grey radiolarian cherts interstratified with tuffs and volcanic breccias	70
Coarse agglomerates and tuff containing a thin band of black shale with graptolites	720
Spilitic lavas associated with breccias and tuff; near the top are thin seams of black shales with fossils. Base not seen	700

The age of the lavas and pyroclastic materials has been determined by the occurrence of graptolites in the interbedded mudstones and shales, and the following species, which have been found at Bennane Head, indicate that the sediments occupy a position within the Zone of *Didymograptus extensus: Dendrograptus diffusus*, *Amplexograptus confertus*, *Temnograptus multiplex*, *Dichograptus octobrachiatus*, *D. reticulatus*, *Didymograptus extensus*, *D. patulus*, *Tetragraptus bigsbyi*, *T. serra*, *T. fruticosus* and *T. quadribrachiatus*. The specimen of *Didymograptus bifidus*, recorded by Lapworth from the shales, is in all probability the early 'tuning fork' graptolite now referred to *D. protobifidus*, which elsewhere makes its entry in this zone. The graptolites are associated with numerous small, horny brachiopods, such as *Acrotreta nicholsoni*.

The lavas are highly decomposed and are usually dark green in colour; they are of two types, and were formerly classed as diabase and diabase porphyrites. A fine development of the porphyritic variety is seen in Stockenray Bay, near Lendalfoot. The rock contains phenocrysts of altered greenish feldspar occurring in a fine groundmass of feldspar, augite, chlorite and ilmenite. Many of the flows exhibit the pillow structure characteristic of spilites. The pillows are well displayed on the shore near Downan Point, south of Ballantrae, where the flows are made up of oval-shaped masses, which are often radially fissured. Each pillow has a concentric arrangement, the compact central portion being surrounded by vesicular outer layers. The pillows vary in size, and the spaces between them are filled with limestone, shale or chert (Pl. IIIA).

UNCONFORMABLE JUNCTION OF UPPER OLD RED SANDSTONE ON VERTICAL SILURIAN ROCKS, SOUTH-EAST SIDE OF SICCAR POINT, COCKBURNSPATH.

A. EILDON HILLS, NEAR MELROSE; FORMED OF SHEETS OF TRACHYTE INTRUSIVE INTO UPPER OLD RED SANDSTONE.

B. LOCH TROOL, KIRKCUDBRIGHTSHIRE: A TYPICAL ICE-ERODED BASIN.

The associated beds of agglomerate are occasionally very coarse, and suggest the proximity of local submarine centres of eruption. An excellent example is the agglomerate of Knockdolian Hill, near Ballantrae. This hill is composed of bedded lavas, overlain by agglomerates and breccias, and a feature of the latter is the absence of any fine-grained matrix, the rock being composed of angular fragments of a vesicular lava presenting the appearance of consolidated macadam. In the coarsest beds some of the included blocks measure 4 ft. across. The agglomerates and breccias have obviously been the products of a cinder-cone. In Stockenray Bay a similar agglomerate includes blocks of a porphyritic rock having a dark and resinous groundmass; it has been described by Teall as a porphyritic tachylite.

Important sections occur in the Craighead inlier on the north side of the Girvan valley, where spilitic lavas showing characteristic pillows are exposed in the cutting at Killochan station and in the quarries at Craighead. The volcanic rocks are faulted against Carboniferous rocks on the south-east side of the inlier, but at the eastern end they are unconformably overlain by the Craighead Limestone. In a quarry at Woodhead Farm the lavas are followed by cherts, black shales and agglomerate.

In the cores of many of the anticlinal folds in the south-western portion of the Northern Belt the succession is similar to that observed near Ballantrae. There is a fine development in the Polshill district, east of New Cumnock. In the lower part the volcanic series comprise lavas, tuffs and agglomerates overlain by mudstones and cherts. In the Leadhills the mudstones contain dark seams which yield graptolites and hingeless brachiopods, and from Ravens Gill the following have been obtained: *Tetragraptus fruticosus*, *T. quadribrachiatus*, *Acrotetra sp.*, *Acrothele sp.*, *Lingulella sp.* and the phyllopod *Caryocaris wrighti*. In the Menock Water, south of Wanlockhead, some of the Arenig rocks are cleaved and markedly schistose. Farther to the south-west an excellent section is exposed in Lagbaes Burn, near Newton Stewart.

East of the valley of the Clyde, near Abington, pillow lavas occupy the axes of the deeper anticlines, and in Raggen Gill and Southwood Burn the volcanic rocks are associated with cherts and greywackes. In the latter stream the lavas are cut by a coarse ophitic dolerite. A similar intrusion is exposed in the Wintercleuch Burn, where the lavas are flasered and schistose along the folds. In Culter Water a large inlier of amygdaloidal diabase is associated with tuff and chert. Farther to the north-east the volcanic rocks are again displayed in several anticlines between Tarth Water, Lyne Water, and Lamancha. Amygdaloidal lavas have been quarried at Noblehouse, but beyond this locality no further exposures are seen. The lava in the Hope Burn, Heriot Water, formerly referred to the Arenig, probably belongs to a higher horizon.

Intrusive Rocks. In the Girvan-Ballantrae region there are numerous intrusions in the Arenig. They comprise serpentine, olivine-enstatite-rock, hornblende-picrite, gabbro, hornblende-granulite, epidiorite, dolerite and granite; they occupy two belts which generally coincide with the direction of strike of the bedded rocks. In the northern part of the area, serpentine and other ultra-basic masses are exposed for about three miles along the coast between Pinbane and Burnfoot and inland by Lochton to Byne Hill. The southern area is narrower, and runs eastwards from near Bennane Head

to Millenderdale. Some of the ultra-basic rocks appear to form a banded complex, as shown by Mr. D. Balsillie. An extensive band of hornblende-picrite ranges north-east from the upper reaches of the Poundland Burn and along the north face of Breaker Hill. The intrusions, especially the ultra-basic and basic masses, have been studied by numerous geologists, including Bonney, Teall, Flett and Balsillie, all of whom have commented on their resemblance to certain rocks of the Lizard peninsula in Cornwall.

The serpentine, which is of various tints, occupies by far the largest part of the area, and has been pierced by dykes of gabbro and dolerite. The commonest type is bastite or lherzolite-serpentine, but dunite, and tremolite-bearing varieties are found at many localities. At the head of Poundland Burn the rock contains picotite in abundance, and occasionally this mineral has segregated in masses of considerable size. The relation of the serpentine to the bedded rocks is obscurely displayed, but where exposed the junction appears to be either a line of fault or of movement; in the latter case the serpentine at the point of contact usually shows flaser structure. Frequently, the movements have produced marked dynamic metamorphism, giving rise in places near the margin of the serpentine to fine-grained hornblende-schist containing garnets or epidote. Balsillie has detected mineral banding in the serpentine, but these structures are distinct from those produced by tectonic movement; and on the hill slopes west of Knocklauch, where the foliated character is well shown, interbanded pyroxenites, bronzites and serpentine-schists may be collected.

Both foliated and non-foliated gabbros are found as dykes in the serpentine. Of the former, examples of hornblende-gabbro occur on Mains Hill, east of Ardmillan; and of the latter, ophitic gabbros are exposed on Byne Hill. The intrusive mass, appropriately designated by Balsillie as 'Bonney's Dyke,' which forms a prominent feature on the foreshore near Lendalfoot, is an ophitic diallage-gabbro. It contains fragments of serpentine and diallagite-pegmatites, the latter rock being well displayed at this locality. The gabbro of 'Bonney's Dyke' is much altered and the feldspars are replaced by prehnite and pectolite. On Fell Hill and Knockdaw Hill there is a white gabbro which has been described as an anorthosite.

Good examples of the foliated type are found east of Millenderdale Farm. These are two dyke-like masses in which the foliation planes dip to the north-west at a high angle. Some portions of the gabbro are schistose and other parts exhibit augen structure. At various places the gabbro is traversed by a fine-grained granulitic rock. It is possible that some of the foliated gabbros are composite intrusions, but on the other hand the foliation may be the result of interstitial movement either during or subsequent to consolidation.

The serpentine is also cut by numerous porphyritic and non-porphyritic dolerite dykes, consisting of plagioclase feldspar and monoclinic pyroxene along with hornblende, biotite, ilmenite and apatite as accessory minerals. The albite crystals are often replaced by prehnite. Dyke-masses form a prominent feature on the shore at Lendalfoot. Some of these may be post-Arenig, but others, such as the gabbros, do not appear to cut the Arenig, and the writer suggests that they belong to an older set of rocks.

The granite of Byne Hill is the best known example of the acid intrusions

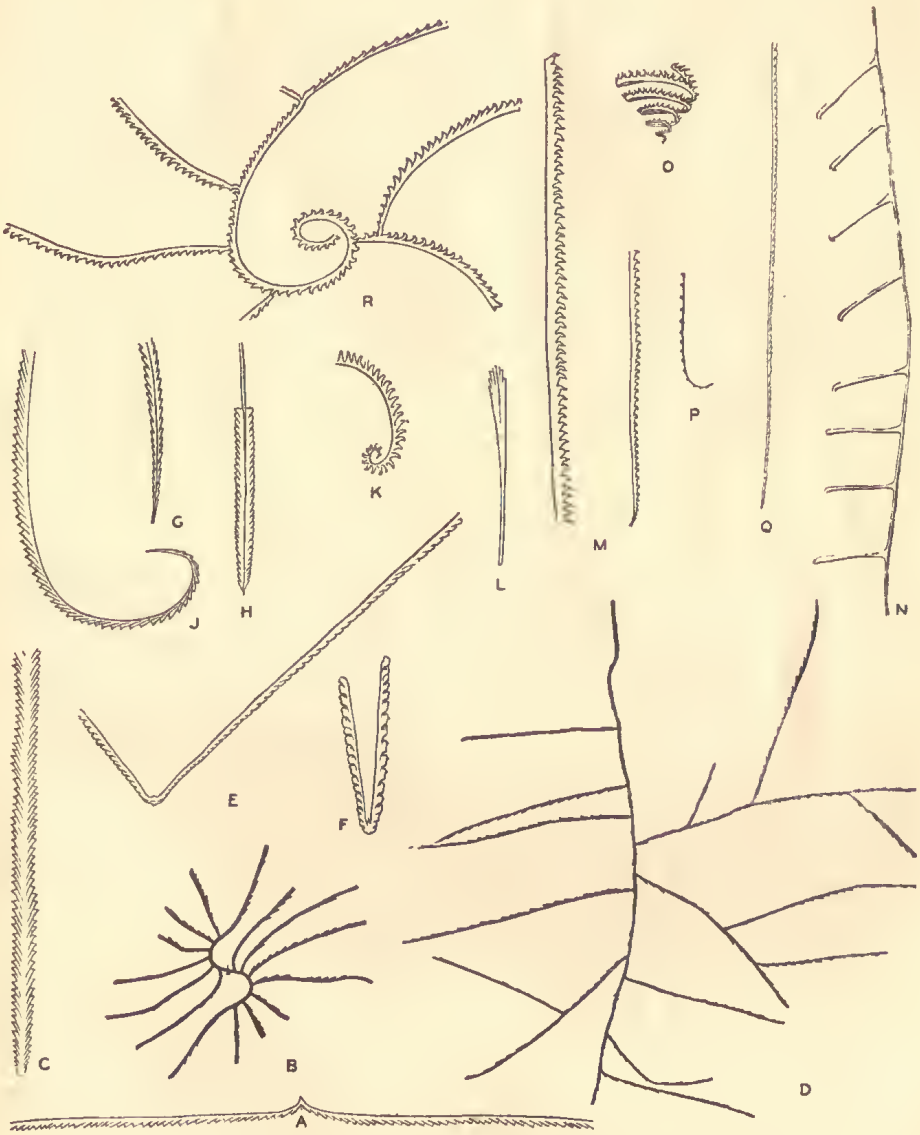

FIG. 4. *Ordovician and Silurian Graptolites*

(All drawings natural size after Elles and Wood)

Ordovician, Arenig Series, **A,** *Didymograptus extensus* (Hall). Glenkiln Shales, **B,** *Nemagraptus gracilis* (Hall). Hartfell Shales, **C,** *Diplograptus* (*Orthograptus*) *truncatus* Lapworth; **D,** *Pleurograptus linearis* (Carruthers); **E,** *Dicellograptus complanatus* Lapworth; **F,** *Dicellograptus anceps* Nicholson. Silurian, Lower Birkhill Shales, **G,** *Akidograptus acuminatus* (Nicholson); **H,** *Diplograptus modestus* Lapworth; **J,** *Monograptus cyphus* Lapworth; **K,** *M. fimbriatus* (Nicholson). Upper Birkhill Shales, **L,** *Cephalograptus cometa* (Geinitz); **M,** *M. sedgwicki* (Portlock); **N,** *Rastrites maximus* Carruthers; **O,** *M. turriculatus* (Barrande); **P,** *M. crispus* Lapworth; **Q,** *M. griestoniensis* (Nicol). Wenlock Series, **R,** *Cyrtograptus murchisoni* (Carruthers).

in the district. It is a biotite-granite with oligoclase, orthoclase and quartz. The granite mass of the Grey Hill is composed of quartz albite, biotite and green hornblende, and is classed as a soda-granite or trondhjemite. A white syenite occurs on the north-west slope of Knockdolian Hill, and on the north face of Knockormal Hill, south of Lendalfoot, there is another rock of a dark green colour presenting a mottled appearance. Formerly, the date of intrusion of the Byne Hill mass was confidently regarded as being post-Arenig and as having been eroded during the deposition of the Benan Conglomerate; but the age is now in doubt, since the granite boulders in the conglomerate are different in composition from the granite forming Byne Hill.

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Caradoc and Ashgill

After the deposition of the Arenig, the region was elevated and subjected to denudation. In the Girvan-Ballantrae district the sections indicate that the uplift had been accompanied by folding, and as a result the sediments of the younger series were laid down on the upturned edges of the Arenig volcanic and sedimentary rocks and serpentine with its associated dykes of gabbro and other masses. But while the unconformable nature of the junction is displayed in the area north of the river Stinchar, current opinion maintains that the sections south of Ballantrae, at Currarie and Portandea, show an unbroken succession. The present writer, however, concludes that there is also a marked stratigraphical break, not only in the southern sections but throughout the Northern and Central Belts. In the region there is no trace of the Llanvirn or Llandeilo Stages; indeed, it is probable that the highest zone of the Arenig is also absent.

The Caradoc and Ashgill Series include a remarkably varied assemblage of sediments. In the Girvan area they consist of massive conglomerates, grits, shales, mudstones and limestones, amounting in all to over 3,000 ft. in thickness, and carrying a rich fauna of corals, brachiopods, lamellibranchs, gastropods and trilobites. The rocks fall within the Barr and Ardmillan Series of Lapworth's classification. Along the northern margin of the Northern Belt a nearly similar thickness of sediments accumulated during the same time interval, but the rocks, though still coarse, become finer in grain and reduced in thickness towards the Central Belt (Fig. 5). In the latter area the deposits are represented by black shales and cherts, in all not more than 200 ft. thick, and are characterized by a fauna consisting almost entirely of graptolites. There is evidence, however, that towards the south-eastern boundary of the Central Belt the shales again pass laterally into coarser rocks, which are not dissimilar from those found in the Northern Belt. It was in the shaly deposits that Lapworth established the Glenkiln and Hartfell subdivisions of the Moffat Series, and a zonal

scheme based on graptolites was worked out by him. It would have been an almost impossible task to correlate highly folded rocks so strongly contrasted as those of the Central Belt and the Girvan area but for the fact that brief episodes occurred during sedimentation when graptolitiferous shales were spread over the whole area; the presence of these beds interstratified with coarse sediments carrying a shelly and trilobitic fauna has been of the utmost importance in working out the order of succession in the Girvan Country.

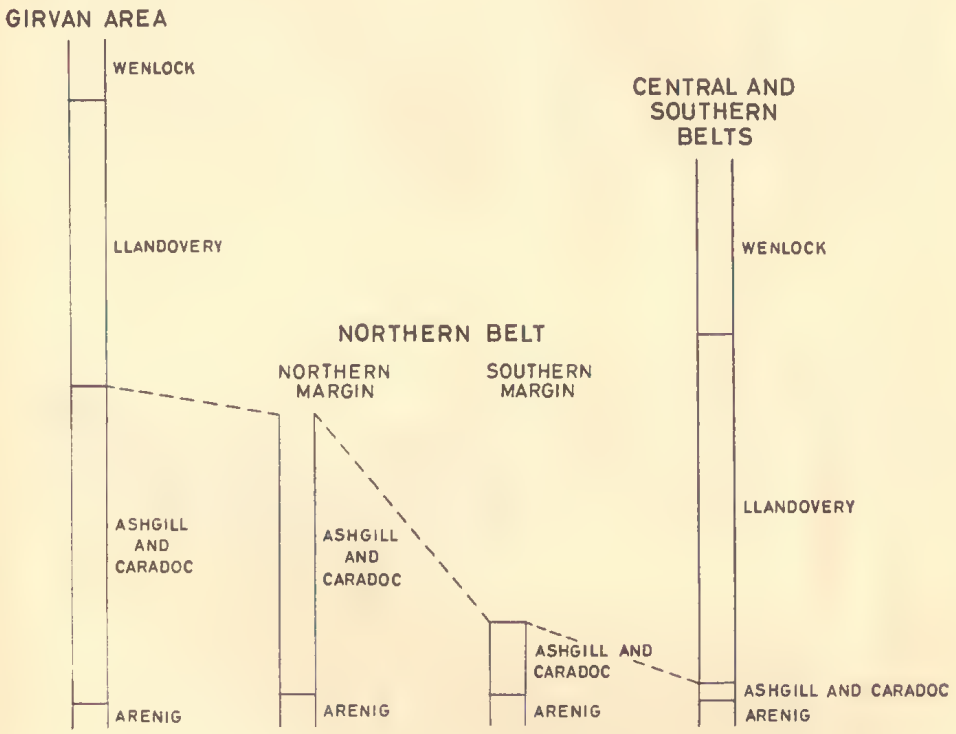


FIG 5. *Table showing relative thicknesses of Ordovician and Silurian strata in the South of Scotland*

Volcanic rocks occur on two horizons, one in the Glenkiln and the other in the lower part of the Hartfell. In neither case do they attain the importance of the underlying Arenig lavas.

During the early stages of the geosynclinal basin in which these deposits were laid down, the greatest amount of subsidence appears to have taken place in the Northern Belt, but later the position of maximum depression shifted towards the north-west, nearer the shore-line. From the manner in which the members of the Barr Series overlap each other, and the further evidence of contemporaneous erosion within the group, it is obvious that the subsidence of the basin was frequently interrupted by minor oscillations; and, as already remarked, brief episodes occurred when graptolite shales were deposited over the whole area. But, while such physical breaks are conspicuous near the margin of the basin, they tend to disappear away from the shore, and it is probable that they are only indicated in the con-

densed deposits of the Central Belt by pauses of sedimentation. Such intervals of non-deposition would explain the presence of crowded layers of graptolites which form a common feature in the Glenkiln and Hartfell Shales at Dobb's Linn and other localities in the Moffat region: all such highly fossiliferous layers imply paucity of sediment. The uniform lithological characters of the shales and cherts in the Central Belt also indicate accumulation over a large part of the basin at some distance from the shore. The lateral passage of the shales into grits and greywackes on the south-eastern side of the belt, however, suggests that the shales were laid down on a floor that acted like a hinge between two areas of maximum subsidence. These conditions lasted to the close of Birkhill time in the succeeding Silurian when the Central Belt wa selevated and its active denudation gave rise to a great accumulation of coarse sediments forming the Queensberry Grits with beds of conglomerate built up of pebbles derived from the Arenig lavas and older rocks of Highland aspect.

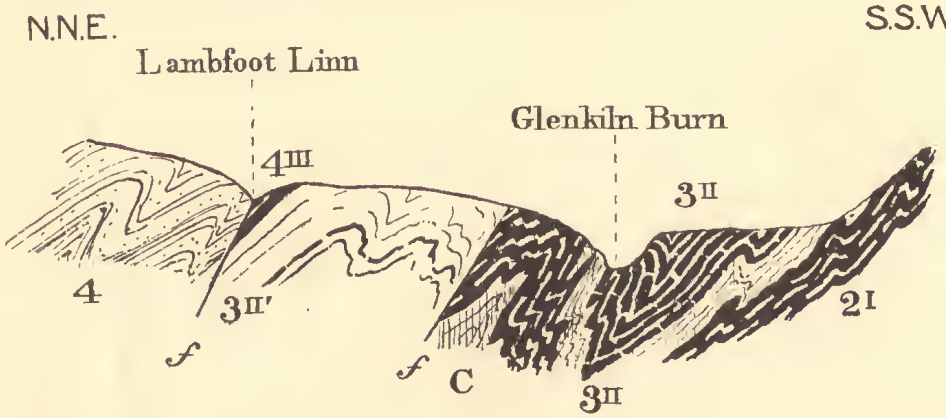


FIG. 6. *Section in Glenkiln Burn, near foot of Lambfoot Linn*

C, Radiolarian chert. 2^{1}, Glenkiln Shales. 3^{II}, Lower Hartfell Shales. $3^{II'}$, Barren Mudstones. 4^{III}, Lower Birkhill Shales. 4, Gala Group. f, Faults.

Until recently the accepted opinion was that in the Central and Northern Belts the Llandeilo formation was represented by a lower series of radiolarian cherts and mudstones and a higher series of black shales with cherts and orange-coloured ashy mudstones (Glenkiln Shales). Although it is probable that the lower series is of Arenig age, the higher has been referred to the ' Upper Llandeilo.' If, however, uniformity with the classification adopted by the Geological Survey in the type areas in South Wales and in Shropshire is to be followed, then the correlation of the Glenkiln Shales with the ' Upper Llandeilo ' cannot be sustained. The base of the Caradoc in Shropshire includes the Zone of *Nemagraptus gracilis*, while at Llandilo in South Wales the Llandeilo Limestone is overlain by shales containing that zonal fossil. The lower part of the Glenkiln Shales, therefore, is the chronological equivalent of these beds and should be placed in the Caradoc. The correlation of the diverse and distinctive deposits of the Barr Series with the Glenkiln Shales is aided by the graptolite fauna of the shales in the Stinchar Limestone Group; that the Barr Series is of Caradoc age

receives additional support from the included shelly and trilobitic faunas.

Glenkiln Shales. The Glenkiln Shales are exposed only in the cores of the deepest anticlinals in the Central Belt. In the type section of Glenkiln (Glenkill of Ordnance Survey map) Burn in Dumfriesshire (Fig. 6), the subdivision is represented by black shales with thin layers of black radiolarian chert and ashy mudstones containing grey siliceous bands. Overlying the mudstones there is usually a band of black shales, seldom more than 2 ft. thick, yielding a rich fauna of graptolites amongst which the following may be noted:—*Climacograptus bicornis*, *C. caudatus*, *C. tubuliferous*, *Corynoides calycularis*, *Dicellograptus moffatensis*, *Dicranograptus nicholsoni*, *D. ramosus*, *Amplexograptus perexcavatus* and *Lasiograptus margaritatus*. The total thickness of the Glenkiln Shales in the Central Belt is about 20 ft. and the following zones are recognized in descending order:

Zones	Characteristic Fossils
Climacograptus peltifer	Climacograptus antiquus, C. peltifer, Dicranograptus ziczac, Lasiograptus bimucronatus, etc.
Nemagraptus gracilis	Nemagraptus gracilis, Didymograptus superstes, Cryptograptus tricornis, etc.

To the north-east of the Glenkiln Burn the subdivision is present in several of the anticlines, for instance, at Craigmichan Scaurs, Dobb's Linn, Ettrickbridgend, Carrifran Burn and Hartfell Score. In the last-mentioned section the shales are associated with lavas and tuffs, and have yielded a characteristic assemblage of graptolites. On account of the pitch of the folds, however, the group is absent in all the anticlines in the area north-east of Ettrickbridgend in the valley of the Ettrick, and in the Douglas Burn in the Vale of Yarrow.

South-west of Moffat between the Nith and the Cree the subdivision is exposed in the Trowdale Glen, Tottlehams Burn and in the sections southwest of Corsehill. In Wigtownshire the shales are present in the cores of many anticlines, but perhaps the best section is that south of the Water of Malzie where specimens of *Nemagraptus gracilis*, *Didymograptus superstes* and *Lasiograptus bimucronatus* are numerous and especially well-preserved.

Over much of the southern edge of the Northern Belt the subdivision exhibits the characteristic features of the type section in Glenkiln Burn, and along the strike the beds show little variation. North-west of this line, however, a lithological change takes place; at first, the strata yielding Glenkiln graptolites consist of dark micaceous shales interbedded in green and grey mudstones; then follows an almost complete replacement of the dark beds by grey shales and greywackes. The change in lithology is prominently displayed along the margin of the belt between Leadburn and the river Clyde. Thus, in Wandel Water, north-east of Abington, the subdivision is represented by black shales carrying a characteristic Glenkiln graptolite fauna, while in the river Clyde, two miles across the strike of the beds, the same fossils are restricted to dark seams interleaved in sandy shales and greywackes. Similarly, to the north-east of the Sanquhar Coalfield and along the northern margin of the belt near the headwaters of the river Girvan, Glenkiln graptolites are found only in thin carbonaceous seams interbedded with greywackes and grits. In this area, too, beds of conglomerate are sometimes present, and are accompanied by evidence of

Geological Survey 1899	Girvan	Northern Belt	Central Belt	Zones	Series
Caradoc	Ardmillan Series: Drummuck Group; Barren or Shalloch Flagstones; Upper Whitehouse Group; Lower Whitehouse Group; Ardwell Group; Balclatchie Group	Lowther Shales with conglomerates and greywackes. Black shales passing laterally into greywackes, shales and conglomerates. Some limestones present. Volcanic rocks in middle zone	Upper Hartfell Shales	Dicellograptus anceps; Dicellograptus complanatus	Ashgill
			Lower Hartfell Shales	Pleurograptus linearis; Dicranograptus clingani; Climacograptus wilsoni	Caradoc
Upper Llandeilo	Barr Series: Benan Conglomerate; Stinchar Limestone Group; Kirkland Conglomerate	Black shales passing north and west into grits, greywackes and shales. Volcanic rocks at Bail Hill, etc.	Glenkiln Shales	Climacograptus peltifer; Nemagraptus gracilis	Caradoc

contemporaneous erosion. Volcanic rocks also occur along a well-defined level, perhaps between the Zones of *N. gracilis* and *C. peltifer* (*see below*). As a result of the replacement of the shales by heavier and coarser sediments, the thickness of the subdivision is greatly increased towards the north-west, and it may be represented by as much as 1,200 ft. of strata.

In the south-western portion of the belt in the fine sections north of Broadsea Bay on the west side of the Rinns of Galloway, and in the neighbourhood of New Luce and Loch Ryan, the change in lithology is also strikingly shown. For instance, at the south end of a section in the Main Water of Luce, Glenkiln graptolites occur in flaggy black shales, while at the north end of the same exposure the fossils are confined to streaks of black shale interleaved in grey shale. Still farther north, in the Cairn Ryan quarries at the entrance to Glen App, the graptolites are confined to thin, dark seams in bluish shales associated with greywackes. At Tannylaggie, Glen Trool and Waterhead, greywackes appear still lower in the succession, and are interbedded with cherts.

Between the Southern Upland boundary fault in Glen App and the river Stinchar there is a strip of country occupied mainly by rocks of Glenkiln age. These consist of mudstones, grits and greywackes (the Tappins Group) 500 ft. thick surmounted by the Glen App Conglomerate, also 500 ft. thick. In a general way the strata resemble their equivalents in the Northern Belt, but the sediments are perhaps coarser. Near the base there is in association with volcanic rocks a fossiliferous mudstone, 6 ft. thick, which has yielded a typical Glenkiln graptolite fauna at Currarie and Portandea. At the latter locality the following fossils were obtained by the Geological Survey: *Climacograptus schärenbergi*, *Dicellograptus moffatensis*, *D. sextans*, *D. patulosus*, *Dicranograptus ziczac*, *Nemagraptus pertenuis*, *Diplograptus* (*Glyptograptus*) *euglyphus* and small horny brachiopods. Near Currarie *Didymograptus superstes* was found in association with a similar fauna, but it is noteworthy that *Nemagraptus gracilis* has not been recorded from these sections. The fauna, however, is nearly identical with that found in association with Glenkiln volcanic rocks on Bail Hill, near Sanquhar, and in the valley of the Clyde; it is probable, therefore, that some of the underlying beds of agglomerate and lava at Currarie and Portandea may belong to the same volcanic episode. That the relationship of the Glenkiln rocks to the Arenig is one of unconformity may be deduced from the absence of the Llanvirn and Llandeilo formations in these sections, thus corresponding of the stratigraphical break in the area now to be described.

Barr Series. North of the fault which passes along the Stinchar valley the chronological equivalents of the Glenkiln Shales in the Girvan area are included in the Barr Series, and the rocks are typically developed in the Benan Burn, near Barr, where the succession is as follows, in descending order:

	Thickness in ft.
Benan Conglomerate, about	500
Stinchar Limestone Group, comprising— green mudstones and shales, compact and flaggy limestones, nodular limestones with shaly partings, impure calcareous flags; in all	60
Kirkland Group, purple sandstones, grits and conglomerates, up to ..	240

The important members of the series are those comprised in the Stinchar Limestone Group. They are highly fossiliferous and have yielded an abundant fauna. The bands of limestone contain the alga *Girvanella* and the foraminifer *Saccamminopsis* in abundance. In the flags and shales associated with the limestone, species of brachiopods are abundant, and include such forms as *Lingula quadrata*, *Schizambon scoticus*, *Orbiculoidea stincharensis*, *Sowerbyella rhombica* var. *conspicua*, *Orthis* (*Heterothis?*) *confinis* and many other species. Of the gastropods, a shell of diagnostic value is *Maclurea logani*, while trilobites are represented by species of *Calymene*, *Encrinurus*, *Illaenus*, *Remopleurides*, *Sphaerexochus* and *Trinucleus*. The occurrence of graptolites belonging to the genera *Climacograptus*, *Cryptograptus*, *Dicranograptus* and *Diplograptus* is of importance; and, but for their presence in the green mudstones and shales, correlation of the Barr Series with the Glenkiln Shales of the Central Belt would have been an exceedingly difficult task, since their respective faunas are otherwise markedly dissimilar.

In the Benan Burn, the Barr Series occupies the northern limb of an anticlinal fold, and each subdivision is well exposed in the stream. The Kirkland Conglomerate at the base is of a purple colour, and in this respect it differs from that of the higher Benan Conglomerate, but otherwise the constituent pebbles are similar. Both beds include fragments of Arenig lavas, gabbro, dolerite, granite, black shale, chert and greywacke, together with rocks of Highland aspect. The Kirkland Conglomerate dips to the north-west, and is followed by purple sandstones and grits with shaly partings.

Forming the base of the Stinchar Limestone Group are calcareous flagstones with *Orthis* (*Heterothis?*) *confinis* and other brachiopods. These shelly flags are followed by the Stinchar Limestone the lower part of which is nodular, and yields the characteristic fossils *Maclurea logani* and *Tetradium peachi*. The upper part is flaggy and contains abundant specimens of *Saccamminopsis* and *Girvanella*.

At the head of the Benan Burn the limestones are overlain by greenish mudstones containing brachiopods and graptolites, the latter being represented by *Climacograptus bicornis*, species of *Dicellograptus* and *Dicranograptus*, *Didymograptus superstes*, *Glyptograptus euglyphus*, *Orthograptus apiculatus*, *Glossograptus hincksi* and *Retiograptus geinitzianus*, a fauna which perhaps indicates a high position in the Glenkiln Shales.

The graptolite-bearing mudstones are followed by the Benan Conglomerate, which dips to the north-west at angles ranging between 25° and 40°. Although there is here no sign of erosion at the base, the sudden change in the character of the sediments suggests that the junction may be discordant. At other localities in the district the conglomerate has overlapped the Stinchar Limestone Group and rests unconformably on the Arenig volcanic rocks. This remarkable bed is the dominant member of the series and forms escarpments on Benan Hill. It is exposed on the Kirkland and Auchensoul Hills and, on account of the marked topographical features it gives rise to, the conglomerate can be easily traced along the line of strike from Benan Hill to the Miljoan and Milton Hills, while from Barr it runs northwards to Penwhapple Glen. Its extension to the north-east beyond the Southern Upland boundary fault is indicated by

the inliers of conglomerate at Linfern Loch, and in the long ridge which culminates in the Big Hill of the Baing, three miles south-east of Straiton, and in the smaller patch at Knockinculloch. In the latter inlier, which is cut by a dolerite sill, are two outcrops of limestone, and these probably represent the Stinchar Limestone.

The succession of the Barr Series, as established in the Benan Burn, may also be seen in various sections exposed in the northern limb of the anticline from Auchensoul Farm to Minuntion. At the latter locality the *Orthis confinis* flags and the overlying limestones with *Maclurea logani* were formerly well exposed, and have yielded an abundant fauna of brachiopods, gastropods and trilobites. On the southern limb of the fold, however, the sequence is highly disturbed, and in the quarries at Dularg the beds are traversed by a fault, which throws down a patch of Lower Old Red Sandstone conglomerate.

Numerous outcrops of the Stinchar Limestone Group are again found in the Assel valley, and on the south side of the river the shelly flags and limestones occupy separate isoclinal folds from Craigwells to Dupin, and may be followed to the south-west of Shalloch Hill north of Daldowie. Farther north they appear between Tramitchell and Brockloch.

In the Tramitchell quarries the Stinchar Limestone, which appears along a faulted anticline, has been extensively quarried. The beds are oolitic in places and are highly fossiliferous, yielding such forms as *Girvanella problematica*, *Saccamminopsis sp.*, *Orthis* (*Heterothis?*) *confinis*, *Maclurea logani*, etc. In this area the Benan Conglomerate covers a broad tract owing to reduplication by folding, and can be traced from Tramitchell to Dinvin Hill. In a section south-east of Brockloch there is evidence of contemporaneous erosion within the series, the Benan Conglomerate resting on an eroded surface of the Stinchar Limestone.

In Dupin Glen a fairly complete section is visible from the *Orthis confinis* flags up to the Benan Conglomerate, and the section exposed in the old quarry 200 yds. south of Craigwells is also of interest, since within the limits of the quarry it shows nearly all the members of the Barr Series. Here, the Kirkland Conglomerate is absent, and the basement beds of calcareous sandstones with *Orthis* (*Heterothis?*) *confinis* rest unconformably on a floor of basic rock. The shelly beds are followed by nodular and compact limestones, which in turn are overlain by green shales with *Diplograptus*, *Lingula* and *Acrotreta*; farther south in the same quarry the graptolitic shales alternate with limy beds. In the succeeding Benan Conglomerate there are numerous pebbles derived from the Stinchar Limestone; similarly, in the Dupin Mid Burn the basal beds of the conglomerate contain pebbles of limestone.

South-westwards from Dupin the Stinchar Limestone Group appears along the margin of the inliers of Arenig volcanic rocks on Shalloch Hill. The beds are much folded and faulted, and both here and near Little Letterpin appear to rest unconformably on the igneous rocks, but the actual junction is not exposed. In the Auchenmaddy Burn, on the other hand, the Benan Conglomerate has overlapped the Stinchar Limestone, and rests unconformably on the Arenig lavas. Evidence of a similar relationship is to be found on Daldowie Hill.

Between Byne Hill and Kennedy's Pass, south of Girvan, the Benan Conglomerate is exposed in an unbroken outcrop; at the first-named locality it appears to rest unconformably on a mass of granite and gabbro, and dips north-west at 60°. On the shore at Kennedy's Pass, Dr. Stewart Henderson has shown that the junction is not faulted, as formerly supposed, but that the conglomerate succeeds a greywacke of the Tappins Group. The road-cutting at this locality is perhaps the best section in the district in which the conglomerate may be studied. The derived fragments include Arenig lavas, gabbro, dolerite, serpentine, granite, chert and black shale embedded in a characteristic green matrix. It is of interest to note that while the majority of the pebbles are of local origin, the granite fragments have been derived from a mass which differs from any exposed in the district.

The Benan Conglomerate also forms a continuous belt by Millenderdale and Aldons, and it is clear that this outcrop and that on Byne Hill and Kennedy's Pass are the relics of two anticlines, the cores of which are occupied by Arenig and other igneous rocks. The Stinchar Limestone is well exposed in Aldons quarry, and the flaggy and compact beds yield many characteristic fossils.

Along the lower part of the Stinchar valley the Barr Series is let down by parallel faults in the midst of Arenig volcanic rocks from Daljarrock by Craigneil to the Water of Tig. Near the ruins of Craigneil Castle the Maclurea Beds occupy an isoclinal fold with *O. confinis* beds on both flanks. The Benan Conglomerate is to be seen near the mouth of the Water of Tig close to Heronsford.

Another isolated patch of the Stinchar Group is exposed at Bougang, near Colmonell. The lowest beds consist of green sandy shales with occasional pebbles, and are followed by flaggy limestones with shaly partings. The relations of the beds to the surrounding serpentine are not visible, but the sediments are unaltered. A similar patch occurs at Knockdolian Barns.

On the north side of the Girvan valley the Benan Conglomerate is exposed in an old quarry north of Trochraigue, and grey shales interleaved with the pebbly layers have yielded *Dicranograptus ramosus*, *Orthograptus calcaratus* and *Cryptograptus tricornis*. The succession at this locality appears to be complicated, since the presence of rocks of Ardwell age is indicated by the occurrence of *Dicellograptus morrisi* in olive green shales north-west of the house.

Hartfell Shales. This subdivision forms the middle member of the Moffat Series, and derives its name from Hartfell 'Score,' near Moffat, in the Central Belt (Fig. 7). The group is about 100 ft. thick, and in the type section falls into two portions, a lower consisting of black shales with thin partings of pale mudstones, and an upper portion (the Barren Mudstones) mainly composed of mudstones with seams of black shale. The conditions of deposition in the Central Belt, therefore, were similar to those which governed sedimentation in this part of the basin during Glenkiln time; consequently, the Hartfell Shales succeed the underlying group without any apparent stratigraphical break. There is, however, an important change in the lithology, to be observed in the upper set of beds in the exposed anticlinal fold at Ettrickbridgend, near Selkirk. Coarse grits appear and

greatly swell out the thickness of the group. The sudden incoming of heavier sediments and marked change of lithology seen in the overlying Birkhill Group appears to indicate movements within the basin (p. 37).

The Lower Hartfell fauna is characterized by a great abundance of species belonging to the graptolite genera, *Amphigraptus*, *Corynoides*, *Dicellograptus*, *Dicranograptus*, *Diplograptus*, *Glossograptus*, *Lasiograptus*, *Leptograptus* and *Pleurograptus* (*Fig.* 4). The hingeless brachiopods *Acrotreta* and *Siphonotreta* and the sponge *Hyalostelia* are also abundant. The mode of occurrence of some of the graptolites is of interest. Some of the bedding-planes are crowded with *Dicellograptus forchhammeri*, others with *Leptograptus flaccidus*, others again with *Orthograptus calcaratus*, *O. vulgaris* and *O. truncatus*. The abundance of graptolites on individual surfaces undoubtedly indicates requent interruptions in the deposition of sediment.

In the Upper Hartfell the fauna is somewhat scanty, and such graptolites as occur are found only in thin dark seams interbedded in the otherwise barren mudstones. In describing the fauna of the Hartfell Shales, Lapworth pointed out ' there is an extraordinary mortality among the graptolites in this division. Not only do the peculiar types of *Pleurograptus* and *Amphigraptus* arise, culminate and decay within the formation itself, but *Dicellograptus*, *Dicranograptus*, *Lasiograptus*, *Glossograptus* and *Leptograptus*—survivors from the Glenkiln Shales—all become extinct before we reach the highest beds.' In other words, a striking palaeontological break occurs at the top of the group which marks the summit of the Ordovician. As will be shown later, an equally noteworthy change in the fauna takes place on the same stratigraphical horizon in the markedly different sediments of the Girvan area.

The following graptolite zones have been established in the Hartfell Shales of the Central Belt, and several of these are traceable through the Northern Belt into the Girvan area:

Zones	Characteristic Fossils
Dicellograptus anceps	Dicellograptus anceps; Climacograptus tuberculatus
Dicellograptus complanatus	Dicellograptus complanatus; Diplograptus socialis, Climacograptus miserabilis
Pleurograptus linearis	Pleurograptus linearis; Amphigraptus divergens, Climacograptus tubuliferus, Dicellograptus elegans, D. moffatensis, Orthograptus quadrimucronatus, Leptograptus capillaris, L. flaccidus, Neurograptus fibratus, etc.
Dicranograptus clingani	Dicranograptus clingani; Amphigraptus radiatus, Climacograptus caudatus, Corynoides calycularis, Dicellograptus morrisi, D. caduceus, D. forchhammeri, Dicranograptus nicholsoni, D. ramosus, Orthograptus calcaratus, O. truncatus, Neurograptus margaritatus, Leptograptus flaccidus, Hyalostelia fasciculus, etc.
Climacograptus wilsoni	Climacograptus wilsoni; Dicranograptus ramosus, D. ziczac, Glossograptus hincksi, and ' Buthograptus laxus '

The zonal subdivisions are well displayed at Hartfell, particularly on the north side of the ' Score.' In the section the Zone of *Climacograptus wilsoni* is composed of grey flinty mudstones and black shales, which yield the index species in association with ' *Buthograptus laxus*,' *Climacograptus schärenbergi*, *Glossograptus hincksi* and other characteristic forms. In the succeeding *Dicranograptus clingani* Zone the shales become more flaggy, and are perhaps

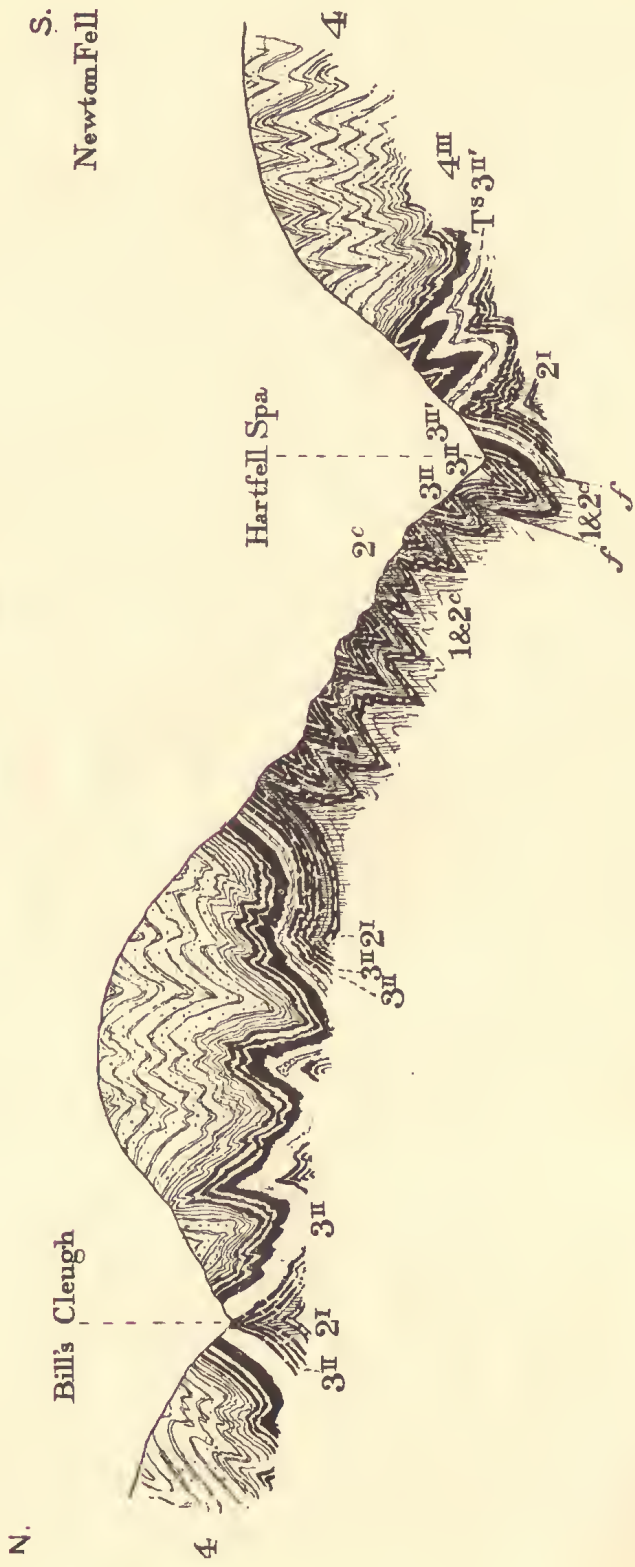


FIG. 7. *Generalized section across the 'Score' at Hartfell Spa*

1 and 2c, Arenig and Glenkiln cherts and mudstones; 2^{I}, Glenkiln Black Shales; 2c, Glenkiln cherts and mudstones; 3^{II}, Lower Hartfell Shales; $3^{II'}$, Barren mudstones; 4^{III}, Lower Birkhill Shales; 4, Gala Group, greywackes and shales; Ts, Volcanic agglomerate; f, Faults.

the most fossiliferous beds in the Lower Hartfell; in turn these are overlain by similar flaggy black shales forming the Zone of *Pleurograptus linearis*. The Barren Mudstones follow, and are associated with a band of volcanic breccia on the south side of the ' Score.'

In nearly all the anticlinal folds, which bring the Moffat Series to the surface in the region to the north-east, the Hartfell Shales are found occupying their normal position between the Glenkiln and Birkhill groups, and in the various sections at Dobb's Linn, Craigmichan Scaurs, Mountbenger and other localities, all the features of the type-section are repeated. In the Selkirk-Melrose area, however, the Glenkiln Shales are no longer exposed in the anticlines owing to the pitch of the folds; but at Lindean the Hartfell Group is perhaps fully represented, since the rare, problematical fossil ' *Buthograptus laxus*,' which is confined to the Wilsoni Zone, has been recorded, and at Leaderfoot Bridge, near Melrose, the occurrence of *Orthograptus basilicus*, *Climacograptus tubuliferus* and *Pleurograptus linearis* testifies to the presence of the Linearis Zone. In the most north-easterly exposure of the subdivision in the Earnscleugh Burn, one of the tributaries of the Leader, near Lauder, grey cherts and black shales yield a typical assemblage of Lower Hartfell graptolites. At none of these localities in this area has it been possible to separate the Barren Mudstones from the overlying Birkhill Group.

As already mentioned, a considerable change in the lithological characters of the Upper Hartfell takes places in the section at Ettrickbridgend, near Selkirk. This denuded anticline lies south-east of a line drawn between Melrose and Dobb's Linn, and is the last fold to bring up the Moffat Shales in that direction. Upwards of 180 ft. of grits are interbedded with green shale containing thin black seams which have yielded *Dicellograptus anceps* and the rare species *Nymphograptus velatus*. In the Lower Hartfell, too, at this locality beds and nodules of limestones are present in the shales, and the change in lithology marks the prevalence of conditions on the south-eastern side of the shale area in the central region similar to those which governed the deposition of the Wrae Limestone in the Northern Belt.

In the country lying south-west of the Nith the Hartfell Shales are present in all the anticlinal folds in which the Glenkiln Group is found. Some of the best localities for graptolites are Bogrie Burn, Glenessland, Water of Urr, Trowdale Glen and in the Cree north of Newton Stewart. In the black shale bands, between the Cree and the Mull of Galloway, good sections are found in the Water of Malzie, Culroy and Clanyard Bay.

Along the southern edge of the Northern Belt the characteristic features of the lower part of the subdivision are repeated in many of the isoclinal folds between the Lammermuir Hills and the important section in Morroch Bay, south of Portpatrick and the shales, particularly at the last locality, carry an abundant and typical graptolite fauna. When the highly folded strata are traced across the strike, however, the fine sediments are seen to be replaced by coarse-grained rocks, in which the characteristic graptolites are confined to black seams interleaved in sandy shales. On certain horizons impure limestones and conglomerates are present and contain a shelly and trilobitic fauna, thus indicating conditions similar to those which prevailed in the Girvan area. The change in the lithological characters of the rocks of the Northern Belt is thus nearly identical with that observed

in the underlying Glenkiln Group of the same region, and the lateral replacement of the shales by heavier and coarser sediments is strikingly shown by the great increase in the thickness of the group. There is an important difference, however; the lateral replacement of fine sediments by coarse took place farther south during Hartfell time, as may be seen in the fine sections between Dounan Bay and Saltpans Bay on the west coast of the Rinns of Galloway.

The Southern Upland boundary fault is well exposed about the middle of Dounan Bay, and numerous branch faults are responsible for the shattering and brecciation of the beds. In Port Long the fault-breccia contains haematite.

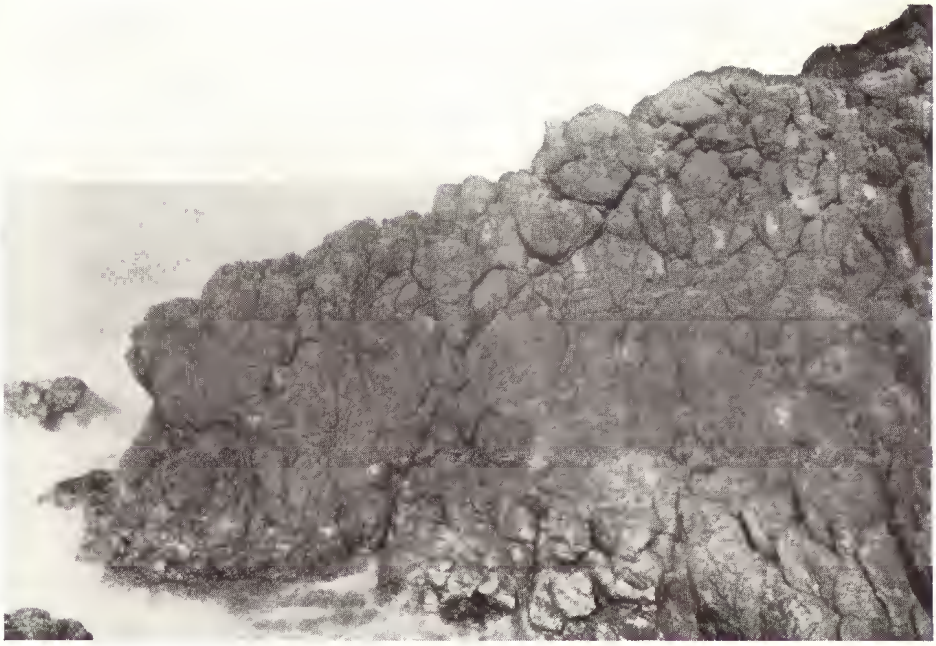
Largely on account of the coarser nature of the sediments all the zonal divisions established in the type section of Hartfell have not been recognized. The *Climacograptus wilsoni* Zone at the base has nowhere been proved in the Northern Belt; similarly, *Dicellograptus anceps* has not been recorded, but its absence may be due to the fact that the highest beds of the Upper Hartfell are possibly missing in this region. The underlying Zone of *Dicellograptus complanatus*, however, has been noted in the Lammermuir Hills. This is the only recorded occurrence of the zone in the north-eastern part of the belt.

Between the Nith and the Clyde there is a coarse conglomerate which has been taken as the base of the Hartfell Group, and it is probably on the same horizon as a similar bed found in the Shinnel and Chanlock Waters, north of Moniaive, in sections on the hills near Carsphairn and in the Afton Water. The pebbles consist of gabbro, granite, felsite, Arenig lava, radiolarian chert, greywacke, black shale and quartzite. In the Glenaylmer Burn, north of Sanquhar, the conglomerate rests unconformably on Arenig rocks, and some of its included blocks of Arenig lava measure 2 ft. across. The similarity of the constituent pebbles suggests that the bed may perhaps correspond to the Benan Conglomerate of the Girvan area.

A pebbly grit known as Haggis Rock typically consists of small fragments of red, green and grey radiolarian cherts and Arenig igneous rocks embedded in a matrix made up of igneous material. This grit probably occupies a definite position in the succession, but the term has been applied too loosely to be of stratigraphical value, since other grits, also called ' Haggis Rocks,' are present on different horizons. It appears likely, however, that in certain localities a ' Haggis Rock ' occupies the position of the conglomerates to which reference has already been made.

The fossiliferous conglomerates of Duntercleuch, Snar, Wallace's Cast and Kilbucho are associated with shales and grits. At the last locality the rock has a greywacke matrix and contains shale-galls and limestone nodules. A combined list of fossils from the various localities includes the following: *Christiania tenuicincta*, *Orthis* (*Harknessella*) *vespertilio*, *Rafinesquina deltoidea*, *Strophomena kilbuchoensis*, species of *Calymene*, *Cheirurus*, *Homalonotus*, *Phacops*, *Trinucleus* and *Remopleurides*. It is, perhaps, possible that an intensive study of the faunas of the conglomerates may prove them to lie on the same stratigraphical level.

The well-known Wrae Limestone and its associated conglomerates and contemporaneous volcanic rocks have in the past been regarded as being



A. PILLOW LAVAS OF ARENIG AGE, DOWNAN, SOUTH OF BALLANTRAE, AYRSHIRE.

B. CRAGS OF OLIVINE BASALT OF CARBONIFEROUS AGE AT SMAILHOLM TOWER, NEAR KELSO.

A. ANTICLINAL FOLD IN PENTON LIMESTONE (LOWER CARBONIFEROUS) AT PENTON LINN, LIDDEL WATER.

B. UPPER CARBONIFEROUS SANDSTONE RESTING UNCONFORMABLY ON ORDOVICIAN SHALES AND GREYWACKES, POLNEUL BURN, KIRKCONNEL

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of Upper Hartfell age. The limestone occurs in the form of nodules and lenticles, and at Wrae, Winkston, Glencotho and Drummelzier has yielded an assemblage of fossils, which includes corals, crinoids, brachiopods, trilobites, etc. Many of the specimens are fragmentary, but the trilobites include a species of *Sphaerexochus*, probably *S. calvus*, which is confined to the Stinchar Limestone and Balclatchie Groups of the Girvan area. This indication that the Wrae Limestone is on a lower horizon than the Upper Hartfell is further strengthened by the occurrence of certain graptolite species in a shale interbedded in tuffaceous grits, 6 to 8 ft. below the higher Stobo Slates. The graptolites include *Dicellograptus elegans*, *Leptograptus flaccidus*, *Neurograptus margaritatus*, *Diplograptus* (*Orthograptus*) *basilicus*, *O. intermedius* and *O. pauperatus*. These indicate a high position in the Zone of *Dicranograptus clingani* (*see* p. 33).

It has already been pointed out that the Zone of *Dicellograptus anceps* has been nowhere recorded in the Northern Belt, and with the exception of the occurrence of *Dicellograptus complanatus* in a tributary of the Sauchet Burn, near Deuchrie Farm, on the northern slopes of the Lammermuir Hills, the Upper Hartfell fauna is practically unrepresented in the north-eastern part of the Northern Belt. Near Abington, however, the Lowther Shales are regarded as of Upper Hartfell age. These are grey and blue shales associated with greywackes and pebbly grits, in all about 800 ft. thick. Occasionally thin ribs of limestone are interleaved in the shales associated with calcareous grits yielding traces of fossils. On lithological grounds the Lowther Group was formerly correlated with the Stobo Slates and the underlying Wrae Limestone, but their equivalence cannot now be sustained.

Ardmillan Series. Although the chronological equivalents of the Hartfell Shales in the Girvan district are not markedly different from those of the Northern Belt, the thickness of the group is greatly increased, in all amounting to 2,800 ft. of strata. The subdivisions are as follows, in descending order:

Drummuck Beds, 400 ft.	Mudstones, calcareous sandstones Sandstones and grits
Barren or Shalloch Flagstones, 800 ft.	Flagstones, shales and mudstones
Whitehouse Group, 300 ft.	Soft green mudstones and grey flagstones with ribs of limestone. Thin band of conglomerate at base (Upper Group). Grey and green shales (Lower Group)
Ardwell Group, 1,200 ft.	Green grits and mudstones Thin-bedded flags and rusty shales Iron-stained shales and mudstones
Balclatchie Group, 100 ft.	Fossiliferous grits and conglomerates, with bands of nodular mudstones

Balclatchie Group. This subdivision has been regarded as forming a transitional set of rocks between the Benan Conglomerate and the overlying Ardwell Group, and includes mudstones, grits and conglomerates. The lowest beds are dark green calcareous nodular mudstones; they are well exposed in a small cliff on the south bank of Penwhapple Burn, and by the road side near Balclatchie Bridge, two miles north-west of Barr. From the latter locality over 100 species of fossils have been recorded, and of these the following are perhaps the more important: *Nidulites favus*, *Dicranograptus*

tardiusculus, *Orthograptus apiculatus*, *Turrilepas scotica*, *Orthis* (*Hebertella*) *balclatchiensis*, *Orthis* (*Platystrophia*) *biforata*, *Orthis* (*Dalmanella*) *girvanensis*, *Rafinesquina deltoidea*, *Leptelloidea llandeiloensis*, etc. Trilobites are remarkably abundant elements of the fauna and are represented by species of *Acidaspis*, *Agnostus*, *Ampyx*, *Asaphus*, *Bronteopsis*, *Cheirurus*, *Cybele*, *Illaenus*, *Lichas*, *Phacops*, *Remopleurides*, *Salteria*, *Sphaerexochus*, *Staurocephalus* and *Trinucleus*. The mudstones are succeeded by green sandstones with a band of fossiliferous conglomerate, the matrix of which is largely composed of sediment derived from Arenig igneous rocks. Many of the characteristic members of the fauna of the underlying mudstone are present.

From Balclatchie Bridge south-westwards to Tramitchell the outcrop of the group is irregular owing to folding, the Balclatchie Beds lying in the synclinal folds of the Benan Conglomerate; and on the western slope of Daldowie Hill the plication of the strata is particularly marked. Beyond the Assel valley towards Millenderdale the Balclatchie Grit is exposed in quarries on the north side of the road near Meikle Letterpin; while in the Millenderdale Burn the trilobitic mudstones may be seen dipping to the north-west at high angles.

On the south-west side of Laggan Gill, Balclatchie Beds plunge with inverted dip beneath the Benan Conglomerate, and the shales, flagstones and limestones are crowded with graptolites and brachiopods. The graptolites are in a fine state of preservation and include *Climacograptus bicornis*, *C. schärenbergi*, *Cryptograptus tricornis*, *Dicranograptus nicholsoni*, *Orthograptus apiculatus* and *Lasiograptus harknessi*.

Another section which has yielded an abundant fauna may be seen on Ardmillan Braes, two miles south of Girvan, where mudstones are exposed in old quarries east-south-east of Ardwell Farm. Here the beds are vertical and in some cases inverted. Again, on the northern slope of Dow Hill, south of Girvan station, similar mudstones have yielded fine suites of characteristic fossils.

On the north side of the Girvan valley, the Craighead Limestone is well exposed in the Craighead quarries, where the following succession may be seen:

Shaly limestone with shaly partings in vertical beds, conglomeratic where resting on Arenig lavas

Greenish brecciated limestone, with basal conglomerate, consisting largely of pebbles of lava, resting on Arenig lavas

Calcareous mudstones in pockets

Arenig pillow-lavas

The section gives a fine illustration of the manner in which the different members overlap each other and successively come to rest on the Arenig lavas. The contemporaneous brecciation of the lower beds of limestone appears to have been brought about by the unstable character of the floor on which the deposits were laid down.

The fossiliferous character of the limestone has attracted the attention of collectors for many years, and extensive lists of fossils have been published by the Geological Survey. Of the fauna the following species may be cited: *Saccamminopsis sp.*, *Climacograptus bicornis*, *Cl. schärenbergi*, *Cryptograptus tricornis*, *Dicranograptus ramosus*, *Orthograptus apiculatus*. The graptolites are found in shaly partings in the highest beds. Of the corals perhaps the

tardiusculus, *Orthograptus apiculatus*, *Turrilepas scotica*, *Orthis* (*Hebertella*) *balclatchiensis*, *Orthis* (*Platystrophia*) *biforata*, *Orthis* (*Dalmanella*) *girvanensis*, *Rafinesquina deltoidea*, *Leptelloidea llandeiloensis*, etc. Trilobites are remarkably abundant elements of the fauna and are represented by species of *Acidaspis*, *Agnostus*, *Ampyx*, *Asaphus*, *Bronteopsis*, *Cheirurus*, *Cybele*, *Illaenus*, *Lichas*, *Phacops*, *Remopleurides*, *Salteria*, *Sphaerexochus*, *Staurocephalus* and *Trinucleus*. The mudstones are succeeded by green sandstones with a band of fossiliferous conglomerate, the matrix of which is largely composed of sediment derived from Arenig igneous rocks. Many of the characteristic members of the fauna of the underlying mudstone are present.

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commonestexamples are *Favosites girvanensis*, *Halysites sp.*, *Lyopora favosa*, *Streptelasma craigense* and *Tetradium peachi*. Crinoids and annelids are represented by fragments of unnamed species, but brachiopods are numerous and include such characteristic forms as *Lingula quadrata*, *Schizambon scoticus*, *Orbiculoidea stincharensis*, *Sowerbyella sericea* var. *craigense*, *Orthis* (*Platystrophia*) *biforata*, *O.* (*Dinorthis*) *flabellulum*, *O.* (*Harknessella*) *vespertilio*, *Camarella peachi* and *Parastrophia scotica*. The lamellibranchs, gastropods and cephalopods are represented by a number of forms, the most important being the gastropod *Maclurea logani*. The trilobites include species of *Encrinurus*, *Illaenus*, *Lichas*, *Sphaerexochus*, *Telephus* and *Trinucleus*. The faunal assemblage clearly indicates the Caradoc age of the limestone; recent investigations by Mr. F. W. Anderson and the writer have proved it to belong to the Balclatchie Group.

Ardwell Group. At the northern end of Kennedy's Pass the Benan Conglomerate is unconformably overlain by members of the Ardwell Group. They are exposed on the Ardmillan shore, where the remarkably folded character of the striped flagstones may be studied. There are also some curious examples of 'curly' bedding which appears to have been produced by movement of sediment prior to consolidation, and in this connexion it is of interest to note that the brecciated limestones of Wrae are on approximately the same horizon. In both instances the structures may have been produced by earth-movements set up by contemporaneous volcanic explosions. It is estimated that the group is nearly 1,000 ft. thick. Inland, they occur in the Penwhapple Burn and with the overlying Whitehouse Group and Barren Flagstones they occupy a considerable part of the country south of the Girvan valley between Millenderdale and Hadyard Hill.

The lowest beds consist of dark grey shales with hard grey ribs and bands of conglomerate. The shales have yielded the following graptolites: *Climacograptus bicornis*, *Orthograptus leptotheca* and *O. apiculatus*. Higher in the succession the beds become more flaggy, and pass into flagstones with thin partings of shale yielding *Dicranograptus ramosus*, *Corynoides calycularis*; whilst in the highest beds exposed on the Ardmillan beach, dark and grey seams contain numerous specimens of *Climacograptus caudatus* and *Orthograptus sp*. The Cascade Beds which succeed this horizon in the Penwhapple Glen, however, are not exposed.

In Penwhapple Burn the lower beds of Ardwell shale are iron-stained, flaggy and much contorted, but dip to the north-west. In addition to *Climacograptus antiquus*, *Cl. schärenbergi*, *Dicellograptus moffatensis?* and *Orthograptus apiculatus*, the shells of *Orthoceras* are found in calcareous bands and nodules. The shales are followed by more flaggy beds with bands of grit, and these in turn are succeeded by shales with *Dicellograptus patulosus*, *Orthograptus apiculatus* and *Climacograptus bicornis*. Still higher are green pebbly grits, which, on account of their forming waterfalls, were termed the Cascade Beds by Lapworth. The grits are associated with dark shales and mudstones with calcareous bands and nodules, yielding *Dicellograptus forchhammeri*, *Neurograptus margaritatus*, *Climacograptus caudatus* and other graptolites.

South of Girvan there are good exposures of the Ardwell Group in the railways cuttings between Girvan and the valley of the Stinchar to the north of Pinmore. Near Meikle Letterpin, flagstones and shales yield

characteristic graptolites in abundance. The beds are also well exposed on Fauldribban Hill, in the Piedmont Glen, on Trowier Hill and in numerous sections near Tralodden. North-eastwards from Knockgerran to Dalamford they occupy a narrow inlier surrounded by Lower Old Red Sandstone, and at the latter place black shales interbedded with grits and sandstones contain graptolites indicating equivalence with the Cascade Beds of Penwhapple Burn.

Whitehouse Group. Lapworth recognized that the beds of this group may be divided into two subgroups, a lower consisting of grey and green carbonaceous shales with *Dicellograptus forchhammeri* and an upper which includes thin bands of conglomerate with derived fossils, grey flagstones with ribs of impure fossiliferous limestone, and soft green mudstones. The line of division between the Caradoc and the Ashgill falls at the conglomeratic base of the upper sub-group. The beds occupy the shore from Ardwell Bay north-eastwards to Shalloch Mill; they are vertical or highly inclined and in some instances inverted. Near Whitehouse members of the upper subgroup are displayed on the beach at low tide, the conspicuous bright red mudstones associated with green and purple shales forming a striking feature. They pass up into highly fossiliferous calcareous grits and shales. To the north of Whitehouse Bay the upper beds are traceable north-eastwards to Port Cardloch, thence across Woodland Point to Woodland Bay and onwards to Myoch Bay. They are highly contorted and the relationship of the strata is extremely complicated owing to inversion and folding.

Opposite Shalloch Mill the following subdivisions have been made out in the upper or Ashgill portion of the group; these are in descending order, but the higher beds are now no longer well exposed:

Dionide Beds	Calcareous sandstones, 6 ft.
Dictyonema Zone	Hard flaggy shales with ribs of grey calcareous rock with *Dictyonema*, etc., 9 ft.
Dicellograptus complanatus Zone	Black shales with seams of grey mudstone and calcareous grit with *Dicellograptus complanatus*, etc., 5 ft.

In addition to the graptolites cited above, the following are some of the characteristic fossils which have been obtained at this locality: *Halysites catenularis, Nematolites grayi, Leptelloidea albida, Strophomena shallochiensis, Tentaculites anglicus* and numerous gastropods and cephalopods. The trilobites include *Agnostus perrugatus, Calymene blumenbachi, Dionide lapworthi, Cyclopyge armata, Illaenus shallochensis, Stygina latifrons, Telephus reedi*, etc.

Near the mouth of Byne Hill Burn, close to Shalloch Mill, Lapworth recorded the presence of graptolites which characterize the *Pleurograptus linearis* Zone; these include *Leptograptus flaccidus, Pleurograptus linearis, Dicellograptus morrisi, Climacograptus tubuliferus* and *Orthograptus quadrimucronatus*. A similar fauna was also obtained by him from the lower part of the group exposed in the Penwhapple Burn. At this locality the beds are inverted and dip to the south-east.

Barren or Shalloch Flagstone Group. On the Ardmillan shore the Whitehouse Group is followed by a series of almost unfossiliferous flagstones and shales with bands of greywacke. The beds are nearly vertical, and are easily

traced along the beach from Whitehouse to near Shalloch Mill, where they are faulted against Llandovery rocks. In the Penwhapple Burn a similar succession occupies the stream for a distance of 1,300 yds. In this section the beds are inverted, and dipping to the south-east they pass beneath the Whitehouse Group, but north of Penwhapple Bridge the flagstones are truncated by a reversed fault which brings them also against the Llandovery. Near the base of the group certain bands of green mudstones south of the foot of Laigh Assel Burn have yielded *Nematolites grayi.*

In the Craighead inlier the flagstones are faulted against the Arenig, Craighead Limestone and Ardwell Group at Craighead and Killochan. In the burn west of Quarrel Hill the group comprises flagstones and shales with *Nematolites grayi* and thin bedded grey micaceous grits, with narrow bands of shale dipping towards the east at a high angle. On the southern limb of the anticline they are again exposed in a burn near Farden, while westwards at Blair a similar succession is seen in an old quarry, and the dip of the beds here indicates that they occupy the northerly limb of the fold.

Drummuck Group. This group is confined to the Craighead inlier, and comprises pebbly grits, sandstones, mudstones and shales which occupy a narrow strip of country from Drummuck eastwards along the Lady Burn, southwards round the slopes of Quarrel Hill and westwards in the direction of Auldthorns.

The lowest beds are exposed on Quarrel Hill where they dip to the east at 30°. The more important members of the group are the olive mudstones which contain an abundance of trilobites, including *Ampyx drummuckensis, Calymene drummuckensis, Cheirurus bimucronatus, Cybele loveni, Dindymene cordai, Dionide richardsoni, Illaenus bowmanni, I. nexilis, Lichas geikiei, L. laxatus, Phacops brongniarti, Phillipsinella parabola, Proetus girvanensis, P. procerus, Remopleurides colbi, Staurocephalus globiceps* and *Trinucleus bucklandi.* The beds are well exposed in the Lady Burn about one mile east of Drummuck Farm, and dip towards the north and north-west at 25°. In a highly fossiliferous locality near South Threave, the zonal graptolite *Dicellograptus anceps* has been found in association with trilobites, brachiopods, lamellibranchs, etc. Near the head of the Lady Burn the mudstones are underlain by a hard greenish-grey calcareous sandstone, the Starfish Bed, which as the result of the indefatigable researches of Mr. J. L. Begg, has yielded a highly interesting trilobite fauna.

Volcanic Rocks in the Glenkiln and Hartfell Groups. Igneous rocks occur on two horizons in the Caradoc strata of the Northern Belt. One of these levels lies within the Glenkiln Shales, while the other is found in the Clingani Zone of the Lower Hartfell. In the Central Belt fine tuffs are interbedded with the Glenkiln Shales at several localities, for instance, at Dobb's Linn and at Trowdale, near Castle Douglas, and these probably represent wind-blown volcanic dust.

Although the Glenkiln volcanic rocks are present in numerous localities in the Northern Belt, extending from the Rinns of Galloway to beyond Gala Water, the best displays of lavas and associated tuffs are those which occur in the neighbourhood of Bail Hill, near Sanquhar. They have been studied by Mrs. V. A. Eyles, to whom the writer is indebted for the following notes: ' The volcanic rocks of Bail Hill are predominantly of pyroclastic origin.

but lavas and minor intrusions are also present. At first believed to be of Arenig age, my examination has shown them to be later than the shales containing graptolites typical of the Upper Glenkiln sediments. The commoner rock-types have dioritic affinities (hornblende-andesites and microdiorites), but one of the most interesting rocks is the so-called augite-tuff, first described by Teall. This tuff contains large and often unbroken crystals of augite, and an examination of thin slices of the rock under the microscope, coupled with a chemical analysis, suggests that it is an intensely auto-brecciated basalt.

'In the centre of the area is a coarse rock of pyroclastic origin containing many fragments of rocks which have no analogues in the district, such as, for example, a remarkable soda-syenite. This mass of agglomerate probably marks the site of a vent; in fact, the complex of volcanic rocks on Bail Hill in all likelihood represents a denuded volcanic pile which later became involved in regional folding.

'A study of a number of tuffs occurring on the same horizon outside the area has shown that in many cases they are composed of materials similar to those of the Bail Hill rocks.' Teall also recognized this close resemblance, particularly with that shown by the augite-andesite tuff of Mains Hill, near Ballantrae. A recent examination of the area led the writer to conclude that a Glenkiln age for the tuff is not improbable. An agglomerate with a thin bed of lava exposed south of Broadsea Bay in the Rinns of Galloway is doubtless on the same horizon as the Bail Hill volcanic rocks, and the occurrence of an assemblage of graptolites typical of the *N. gracilis* Zone in shale fragments enclosed in the agglomerate suggests a *peltifer* age for the rocks. To the same period must be referred the tuffs and breccias which are found in the area between the Euchan and Kellow Waters near Sanquhar. My colleague, Mr. R. Eckford, informs me that the rocks are closely associated in the Poltallen Burn with shales yielding Glenkiln graptolites.

North-east of Bail Hill a narrow outcrop of biotite-hornblende-andesites is exposed at several localities between Kiln Burn and Culter in the valley of the Clyde. They have recently been studied by Mr. Eckford and Mr. Mowbray Ritchie, who refer the lavas to a Glenkiln horizon. A short distance south of Culter village there are one or two beds of augitic ash, which, although the crystals of augite do not attain the same dimensions, closely resemble the tuffs of Bail Hill bearing the same mineral. The pyroclastic rocks are perhaps not more than 50 ft. thick, and Messrs. Eckford and Ritchie find that the associated shales contain a Glenkiln fauna. As already mentioned (p. 11) the so-called Arenig lavas exposed in the Hope Burn, near Heriot, are probably also of Glenkiln age.

The higher set of volcanic lavas and tuffs occur only in the valley of the Tweed in Peeblesshire and have been appropriately named the Tweeddale lavas. They were formerly assigned to the Upper Hartfell, but Messrs. Eckford and Ritchie have proved them to lie within the Zone of *Dicranograptus clingani* of the Lower Hartfell.

The lavas are exposed in numerous localities between Winkston Hill, two miles north of Peebles, and Glencotho, a distance of fifteen miles along the line of strike, and are associated with tuffs, limestone-breccias, grits, cherts and shales. They attain their greatest development on Winkston Hill, where the beds are at least 100 ft. thick. On Hamilton Hill they are perhaps not

more than half that amount, and towards the south-west they greatly diminish in thickness; at Wrae Hill the lower lava is only 15 ft., while at Drummelzier it is barely 1 ft. thick.

The position of the lavas in the succession is clearly indicated at Wrae Hill. Here, the lower lava is followed by a greenish calcareous ash, 40–50 ft. thick, which is full of blocks of trachytic lava and contains two flows of a similar rock. Higher up in the ash is a limestone breccia 15 ft. thick, and at Wrae and Drummelzier the larger blocks have been quarried. The brecciation of the limestone is believed to be due to contemporaneous explosive action. The gritty beds of ash are overlain by the Stobo Slates, and from a thin band of black shale and chert interbedded in some tuffaceous grits 6–8 ft. below the slates at Stobo the following graptolites have been obtained: *Dicellograptus elegans*, *Leptograptus flaccidus*, *Diplograptus* (*Orthograptus*) *basilicus*, *D.* (*Ortho.*) *intermedius*, *D.* (*Ortho.*) *pauperatus* and *Neurograptus margaritatus*, an assemblage which indicates a fairly high position in the Clingani Zone.

At Hamilton Hill and Winkston the ash appears to be replaced by volcanic grits and argillaceous tuffs. These are exposed along the side of the main road between Edinburgh and Peebles. Banded and perlitic types are found at Winkston, and a dark glassy lava contains riebeckite. On Hamilton Hill a lava appears to overlie the limestone and shows typical trachytic structure.

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Continued on p. 46

III. SILURIAN

Llandovery

THIS SUBDIVISION OF the Silurian is represented in the Central Belt by two strongly contrasted sets of rocks: a thin black shale group below and a thick arenaceous group above, comprising conglomerates, grits, greywackes and grey shales. To these the names Birkhill Shales and Gala Group have been applied in the Moffat–Galashiels area. So quickly do the Birkhill Shales pass laterally into greywackes, grits and subordinate bands of sandy shale, that the term, except in a chronological sense, soon becomes inappropriate. The base of the Llandovery coincides with the northern edge of the belt, while the Hawick Rocks of the Gala Group pass conformably beneath the Wenlock occupying the Southern Belt.

No representatives of the formation have been found in the Northern Belt, but in the Girvan district the equivalents of the Birkhill Shales consist of a varied assemblage of rocks, comprising conglomerates, sandstones, shelly grits, limestones and shales. Further, to emphasize the lithological differences between the two areas, the fauna of the Birkhill Shales, like that of underlying Hartfell and Glenkiln Groups, consists mainly of graptolites, while the Girvan representatives contain abundant remains of corals, brachiopods, molluscs and trilobites. Graptolites also occur, but are confined to relatively narrow horizons separated by great thicknesses of strata; and, as in the case of the two underlying subdivisions of the Moffat Series, correlation of the two areas would have been extremely difficult but for the occurrence of these graptolitic shales. They have enabled the two areas to be linked, and the highly complicated structures successfully to be worked out at Girvan. In the higher Llandovery rocks there are no such strongly contrasted elements. A similar set of sediments is common to both areas, though it is to be remarked that the rocks are coarser in the Central Belt and become finer towards the north-west: a reversal of the conditions which had prevailed over the region since Glenkiln time. No volcanic rocks of Silurian age are known in the Uplands.

Birkhill Shales. This group forms the highest member of the Moffat Series of Lapworth, and is well exposed in the type locality of Dobb's Linn, near Birkhill Cottage, at the head of Moffat Water (Fig. 8). Two subdivisions of almost equal thickness are recognized. In the lower Birkhill, which is 52 ft. thick, the shales are black, but contain thin seams of white clay and ribs of impure limestone; in the Upper Birkhill the clay-seams are so numerous as to impart a black-grey aspect, a character which serves to distinguish them readily in the field. Graptolites occur abundantly throughout the group, and although the shales appear to follow the Barren Mudstones of the underlying Hartfell with apparent conformity, there is a striking palaeontological break at the base. As Lapworth remarked, ' Of the numerous genera of compound Graptoloidea which gave such a varied character to the fauna of the Glenkiln Shales . . . and the Hartfell division, not one passes up into the Birkhill Shales. Here, on the other hand, the extraordinary prevalence of Monograptidae upon every zone is in striking

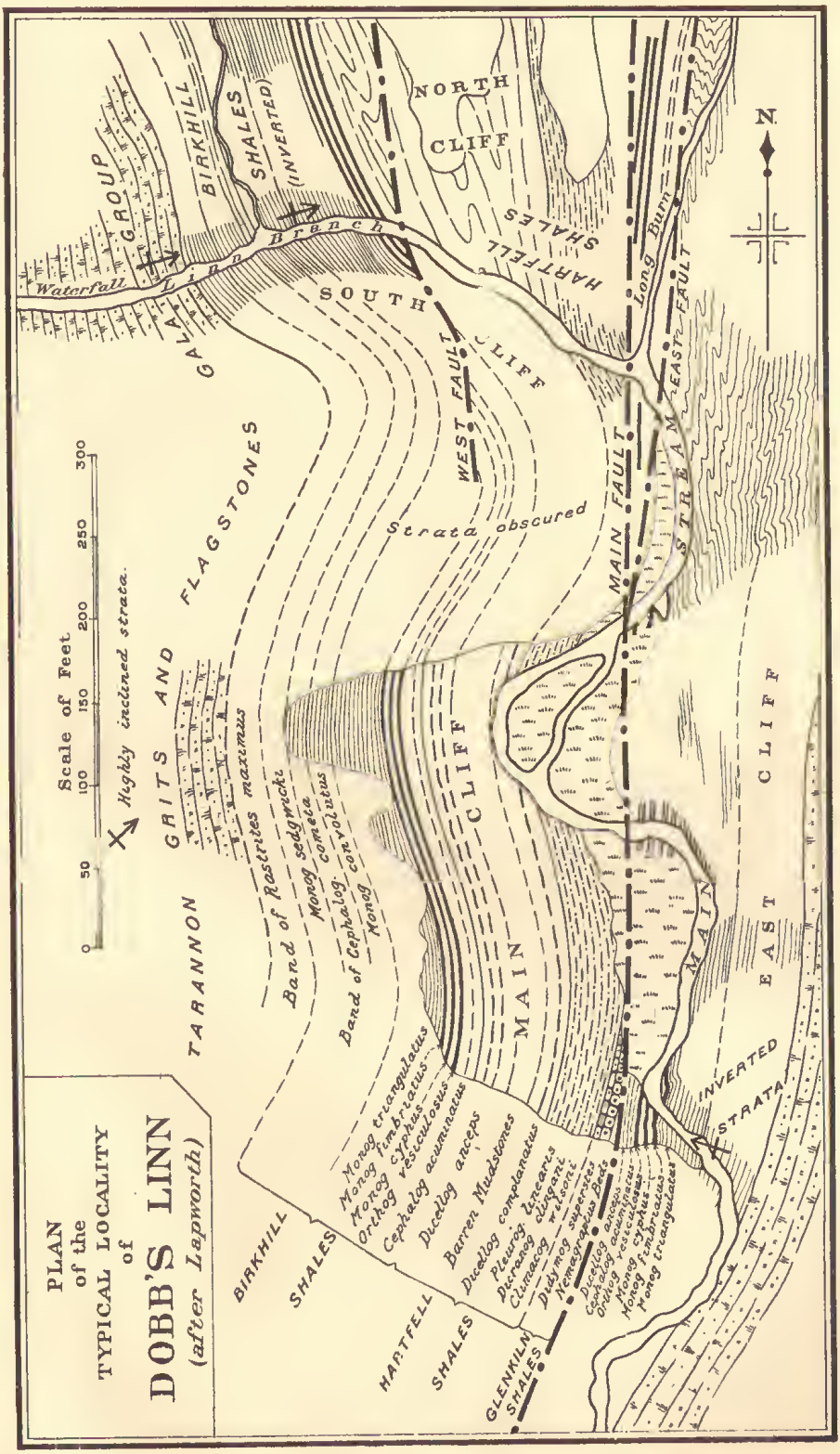

Fig. 8. *Main Cliff, Dobb's Linn*

contrast to what occurs in the inferior division, where not the slightest trace of any form of the family has ever been detected.

'The two genera *Monograptus* and *Rastrites* swarm abundantly in all except the lowest zone of the Birkhill Shales, and with the more sparingly distributed genera *Diplograptus*, *Climacograptus* and *Retiolites* (together with a few scattered forms of Crustacea and Spongidae) constitute the whole of the fossils of the group.' As a result of his study of the graptolites, Lapworth established the following zones. These are excellently exposed in the Main Cliff, the lateral gorge and the Long Burn.

Zones	Characteristic Fossils
Rastrites maximus	Rastrites maximus, Monograptus nudus, M. turriculatus, M. halli, Petalograptus altissimus, etc.
Monograptus sedgwicki	M. sedgwicki, M. clingani, M. nudus, M. leptotheca, M. decipiens, Rastrites hybridus, Climacograptus normalis, C. hughesi, Glyptograptus tamariscus, Petalograptus folium, Discinocaris browniana
Cephalograptus cometa	Cephalograptus cometa, M. argutus, M. limatulus, M. jaculum, M. leptotheca, M. lobiferus, M. tenuis, Rastrites capillaris, R. hybridus, Climacograptus hughesi, Glyptograptus sinuatus, G. tamariscus, Petalograptus folium
Monograptus gregarius	Monograptus gregarius, M. cyphus, M. fimbriatus, M. leptotheca, M. lobiferus, M. sandersoni, M. atavus, M. triangulatus, Climacograptus innotatus, Cl. normalis, Dimorphograptus physophora, Petalograptus folium, Rastrites peregrinus, Discinocaris browniana, Dawsonia campanulata
Diplograptus vesiculosus	Diplograptus (Orthograptus) vesiculosus, Akidograptus acuminatus, Climacograptus rectangularis, C. medius, Dimorphograptus swanstoni, Monograptus acinaces, M. atavus
Diplograptus acuminatus	Akidograptus acuminatus, Dimorphograptus confertus, Climacograptus rectangularis, Dawsonia campanulata

In the hill country between Moffat Water and the lower reaches of the Ettrick, the Birkhill Shales are repeated again and again in a series of sharp anticlinal folds (Fig. 1) and nowhere is the remarkably folded character of the rocks better seen than in the Selcoth Burn section at Craigmichan Scaurs, where the black shales occupy a succession of isoclinal folds in the midst of the younger greywackes. In similar fashion the shales are repeatedly brought to the surface in the region to the south-west as far as the Mull of Galloway. As a rule the shales are greatly faulted and shattered in all the anticlines.

When traced along the line of strike, that is from north-east to south-west, the shale group is seen to remain remarkably constant in thickness, and even graptolitiferous seams often not more than an inch in thickness continue almost unchanged for many miles. For example, the shales in the Melrose–Lindean band in the north-east are nearly identical with the equivalent beds at Dobb's Linn, and similarly at Glenkiln and in other anticlines south-westwards to Clanyards Bay in the Rinns of Galloway, the characters of the type section are maintained throughout the entire length with little variation.

But when the beds are followed across the strike, either to the north-west or to the south-east, changes in lithology and thickness take place immediately. Thus, in the Entertrona Burn in the Upper Ettrick, black grits and

greywackes appear in the higher Birkhill division. The section at Ettrickbridgend, near Selkirk, shows still greater variation: Upper Birkhill Shales have been replaced by greywackes, flags and shales resembling the higher Abbotsford Flag type, and in the lower division greywackes are interbedded with black shales. To the north-west of the Melrose–Lindean band, grits and greywackes are intercalated near Innerleithen, in the Lugate Water, and in the Gala Water, near Fountainhall. In the last-named district thin seams of shale yielding graptolites characteristic of the zones ranging from that of *A. acuminatus* upwards to the *Monograptus sedgwicki* Zone are interstratified with conglomerates, grits, greywackes and sandy shale.

In the Hartfell section lying to the north-west of Dobb's Linn black shales of the Gregarius Zone are followed by massive grits resembling the higher Gala rocks. Similar modifications are to be observed in the group throughout the region between the upper reaches of the Clyde and the Cree in Wigtownshire. At the Bridge of Cree near Newton Stewart the whole of the Birkhill Shales appears to be represented by greywackes and shales, and close to the northern boundary near Glenluce the lowest zonal graptolites are found in shales interbedded with greywackes. But perhaps the best sections in which the changes in lithology may be studied are those of the Rinns of Galloway. As already mentioned, the Lower and Upper Birkhill Shales in Clanyards Bay closely resemble the equivalents in Dobb's Linn. In Drumbreddan Bay to the north the Sedgwicki Zone is represented by grey shales and limestone nodules, and still farther in the same direction the replacement of the shales by coarse sediments is almost complete.

Newlands Series. In view of the progressive change which takes place in a north-westerly direction, it is not difficult, in the absence of Llandovery rocks in the Northern Belt, to visualize the character of the early Silurian sediments which formerly had occupied this tract. The rocks must have been closely similar to those of the underlying Hartfell division, and so form passage beds into the sharply contrasted equivalents of the Birkhill Shales in the Girvan district. The latter occupy three isolated areas to the north and south of the Girvan valley: (1) the Craighead inlier, (2) a narrow belt extending from Saugh Hill by Camregan to Hadyard Hill and (3) the shore at Craigskelly and Woodland. The rocks include conglomerates, shelly sandstones, limestones and shales, and form the Newlands Series, in which Lapworth established the following subdivisions in descending order:

Camregan Group, 200 ft.	Rastrites maximus shales Camregan grit and limestone Rhynchonella grits
Saugh Hill Group, 500 ft.	Monograptus sedgwicki shales Saugh Hill sandstones and grits Woodland Beds, comprising:— On the south side of the Girvan valley: *c.* Diplograptus modestus and Monograptus gregarius shales *b.* Woodland limestone *a.* Craigskelly conglomerate In the Craighead inlier: *b.* Monograptus gregarius shales *a.* Pentamerus grits
Mulloch Hill Group, 350 ft.	Glenwells shales Mulloch Hill sandstone Mulloch Hill conglomerate

Mulloch Hill Group. The various members of this subdivision are well seen in the Craighead inlier. The basal conglomerate is mainly composed of pebbles of Arenig volcanic and associated plutonic rocks, chert and quartzite embedded in a sandy matrix of a dull purple colour. Fossils obtained from the conglomerate at Quarrel Hill are mainly brachiopods belonging to the genera *Orthis*, *Leptaena* and *Strophomena*, none of which is characteristic of the underlying Ardmillan Group. The palaeontological break, although accompanied by physical disconformity, is here as striking as at Dobb's Linn.

The conglomerate is succeeded by soft, greenish-tinted sandstones passing up into yellow sandstones and mudstones (Mulloch Hill Sandstone). They are exposed on the road from North Threave to High Newlands and Rough Neuk, where they dip north-east at an angle of 20°. In contrast to the underlying conglomerate the beds are highly fossiliferous, and the following species may be taken as characteristic: *Nidulites favus*, *Heliolites interstinctus*, *'Petraia' subduplicata*, *Pinacopora grayi*, *Coelospira hemisphaerica*, *Barrandella undata*, *Orthis* (*Schizophorella*) *mullochensis*, *Rafinesquina expansa*, *Camarotoechia llandoveriana*, *Stricklandinia mullochensis*, *Leptelloidea scissa*, *Sowerbyella duplicata*, *Conularia sowerbyi*, *Calymene blumenbachi*, *Encrinurus punctatus* and *Illaenus thomsoni.*

The shelly sandstones are followed by green and blue concretionary mudstones (the Glenwells Shales) well exposed in the Glenwells Burn. From certain striped shales interbedded in the mudstones Lapworth recorded *Akidograptus acuminatus*, *Climacograptus normalis* and *Monograptus atavus.*

Saugh Hill Group. In the Craighead inlier two subdivisions of this group are developed where the Silurian is truncated by a fault at the margin of the Carboniferous rocks in the Girvan valley. These are the Pentamerus Grits of Newlands and the *Monograptus gregarius* Shales of Glenshalloch. Unfortunately their relation to the Mulloch Hill Group is not displayed, though it is clear that they form the highest zones of the Llandovery present in the inlier.

The Pentamerus Grits consist of yellow calcareous sandstones and flags with bands of conglomerate. The best section is exposed in a stream 250 yds. north-east of Newlands where, in addition to *Barrandella* (*Pentamerus*) *undata*, the following are characteristic fossils: *Halysites catenularis*, *Schuchertella applanata*, *Stricklandinia lens*, *Pholidops implicata*, *Cyrtolites*, *Platyceras*, *Orthoceras*, and the trilobite genera *Bronteus*, *Calymene*, *Cheirurus*, *Encrinurus*, *Lichas*, *Phacops* and *Staurocephalus.*

The succeeding *Monograptus gregarius* Shales are to be seen near Glenshalloch and in the west branch of the Baldrennan Burn. They consist of highly folded, flaggy, black and grey striped shales, and the following graptolites found in thin dark seams clearly indicate the equivalence of the beds to the *M. gregarius* Zone of the Birkhill Shales: *Monograptus gregarius*, *M. argutus*, *M. crenulatus*, *M. fimbriatus*, *M. leptotheca*, *M. atavus*, *Climacograptus normalis*, *Glyptograptus tamariscus*, *Petalograptus palmeus* and *Rastrites peregrinus.*

On the south side of the Girvan valley, the Llandovery rocks extend from Saugh Hill by Penwhapple Glen to Hadyard Hill, and are separated

from the Barren Flagstones by a strike fault. This dislocation here forms the southern boundary of the Silurian. The strata are isoclinally folded and the Llandovery rocks appear to dip beneath the Barren Flagstones and Ardwell Flags, an appearance which misled many geologists in the early days of the science.

In Penwhapple Glen, green and grey calcareous flags and shales are the oldest Silurian strata exposed, and from them Lapworth obtained *Pentamerus sp.*; probably, therefore, the rocks are equivalent to part of the Woodland Limestone seen on the shore south of Girvan. They are followed by black mudstones and shales of more than one horizon containing *Monograptus gregarius, M. crenulatus, M. leptotheca, Climacograptus normalis, Mesograptus modestus, D. tamariscus, D. hughesi, Petalograptus palmeus* and *Dimorphograptus swanstoni.* The Gregarius Shales form a prominent feature and have an inverted dip to the south-east. They are followed by the Saugh Hill Grits, which at the type locality on Saugh Hill contain bands of conglomerate and a breccia with angular fragments of grit and shale.

The grits are succeeded by grey or greyish-green and black mudstones and shales forming the highest members of the Saugh Hill Group, and are well exposed in the Penwhapple Glen about 400 yds. south of the foot of Penkill Burn. In the lower part graptolites are especially abundant, and the shales have yielded an assemblage typical of the *M. sedgwicki* Zone of the Birkhill Shales: *M. nudus, M. intermedius, M. sedgwicki, M. convolutus, Petalograptus ovatus* and *Rastrites peregrinus.*

Camregan Group. The shales of the Sedgwicki Zone are followed by grits, impure limestone, shales and mudstones. They are exposed in the gorge below Camregan plantation, where they are inclined at high angles to the south-east. The lowest beds are massive grits and flags, containing casts of Rhynchonellids. They are followed (in inverted order) by flagstones and limestones, and these in turn are succeeded by fossiliferous calcareous shales and mudstones. From the fauna recorded the following may be quoted: *Orthis* (*Plectorthis*) *rustica, O.* (*Bilobites*) *biloba, Brachyprion walmstedti, Pentamerus oblongus, Eospirifer plicatellus, Cyrtia exporrecta, Rhynchospira camreganensis* and several species of *Orthoceras.* Of the trilobites *Acidaspis bispinosus, Bronteus andersoni, Calymene blumenbachi, Cheirurus trispinosus, Encrinurus punctatus, Illaenus murchisoni* and *Phacops elegans* are characteristic species.

The shales are overlain by purple and green mudstones with a seam of dark shale yielding graptolites characteristic of the *Rastrites maximus* Zone of Dobb's Linn; *Rastrites maximus, Monograptus nudus, M. runcinatus, M. turriculatus* and *Petalograptus palmeus.* The purple mudstones are followed by massive grits, which were regarded by Lapworth as forming the highest member of the group, but it is more than likely that they should be included in the Abbotsford Flags or perhaps in the higher Queensberry Grits.

In the area lying to the east of Penwhapple Glen, the Gregarius Shales and Saugh Hill Grits are cut out by an east-west fault, but in the Penkill Burn good sections of the Camregan Beds, consisting of calcareous bands and yellow fossiliferous grits, may be seen close to the road leading to Barr village. Again, in the Bargany Burn the shelly and trilobitic mudstones yield a rich fauna of brachiopods, trilobites, etc. The mudstones are fol-

lowed, as in Penwhapple Glen, by similar rocks with dark seams yielding *Rastrites maximus*, *Monograptus nudus* and *M. turriculatus*.

The higher fossiliferous grits of the Camregan Group are again exposed in a quarry near the south-east corner of Camregan Wood and are crowded with the brachiopods, *Pentamerus oblongus*, *Camarotoechia llandoveriana*, *Coelospira hemisphaerica* and the trilobites *Calymene blumenbachi*, *Encrinurus punctatus* and *Phacops elegans*.

On the shore south of Girvan, the basal conglomerate of the Saugh Hill Group forms the prominent feature known as the Horse Rock at Shalloch Forge. It is 50 ft. thick, and rests unconformably on flagstones and shales of the Ardmillan Series. The pebbles consist of cherts, greywackes and gneissose rocks embedded in a green matrix, and the pebbly layers are interbedded with thick bands of green grit. The conglomerate apparently occupies a lower position than any of the Llandovery beds of Penwhapple Glen or at Saugh Hill, and in appearance and boulder-content it is identical with the conglomerate at Corsewall Point at the northern end of the Rinns of Galloway.

In the islet of Craigskelly, which has given its name to the bed, the conglomerate is associated with grits yielding *Atrypa reticularis*, *Coelospira hemisphaerica* and *Strophomena*. It is followed by calcareous flags or impure limestone (Woodland Limestone) containing *Alveolites labechei*, *Favosites gothlandicus*, *Stricklandinia lens*, *S. lirata* and other brachiopods.

Next in ascending order come the Gregarius Shales with thin dark seams yielding the following graptolites: *Mesograptus modestus*, *Climacograptus normalis*, *Monograptus cyphus*, *M. atavus* and species of *Dictyonema*. They are succeeded by conglomeratic sandstones with white pebbles, the lowest beds containing angular fragments of shales derived from the underlying beds. The sandstones are perhaps the equivalent to the Saugh Hill Grits.

At Woodland Point and in Woodland Bay, south of Craigskelly, the following beds are seen in descending order:

Saugh Hill Sandstone	Scart grits and conglomeratic sandstones Quartz conglomerate
Woodland Beds	Green and black shales with *D. modestus* Pentamerus limestone and shales (Woodland Limestone) Craigskelly conglomerate

In this section the Woodland Limestone, which here consists of about 30 ft. of calcareous flags or limestones, is highly fossiliferous, and long lists of fossils from this locality have been published by the Geological Survey. The specimens include sponges, corals, brachiopods, lamellibranchs, gastropods, cephalopods and trilobites.

Gala Group. The striking difference in lithological facies, which is observed when the shales of the Moffat Series of the Central Belt are compared with their equivalents in the Girvan area, disappears in the Gala Group. In both areas the subdivision includes flags, grits, bands of greywacke and shales in which the effects of contemporaneous sediment flowage are often well displayed; much of the central region, however, is occupied by coarse-grained greywackes with bands of conglomerate, and evidently denotes a considerable shallowing of the basin (p. 42). The broad area of

the outcrop is the result of the intensive folding of the strata which, as has been shown, brings the Moffat Series repeatedly to the surface. The plications are grandly displayed in the cliffs between Cockburnspath and St. Abb's Head, and it was a study of these sections that led Hall to conclude that the folds were the result of powerful lateral compression (p. 3).

The higher Llandovery strata of the central region are included in the Gala Group of Lapworth's classification. It has been estimated that the thickness of the various members is between 3,000 and 4,000 ft. Although generally unfossiliferous, sandy shales interleaved in the greywackes have yielded graptolites which enable correlation to be made with part of the Tarannon Beds of the type area in Wales.

In the Moffat district the Gala Group is divided as follows in descending order: Grey, green and red shales with brown flags and micaceous greywacke bands (Hawick Rocks), greywackes and shales with massive grits and bands of conglomerate (Queensberry Grits) and purple and grey flags and shales (Abbotsford Flags). A similar three-fold division can be made out in other parts of the Central Belt and in the Girvan district. Three graptolite zones have been recognized:

Zones	Characteristic Fauna
Monograptus griestoniensis	M. griestoniensis, M. marri, Retiolites geinitzianus, etc.
Monograptus crispus	M. crispus, M. spiralis, Petalograptus altissimus, etc.
Monograptus turriculatus	M. turriculatus, M. exiguus, M. marri, M. galaensis

In the lateral gorge at Dobb's Linn, grey shales are well displayed at the waterfall, where with inverted dip they rise from beneath the beds of the *Rastrites maximus* Zone of the Birkhill Shales. To the north and east of Dobb's Linn the Abbotsford Flag type of sediment increases in thickness, probably at the expense of the Upper Birkhill shales, and thus marks the change in lithology which is observed when the Llandovery rocks are traversed at right angles to the strike. In other words, part of the Abbotsford Flags of some localities may be equivalent to a portion of the Birkhill Shales.

The Queensberry Grits which follow comprise massive grits, greywackes and shale, and they are constantly repeated by a series of inverted folds, the prevalent dip being to the north-west. As a result of the intensity of the folding a schistose structure has been developed in the rocks of part of this area. The bands of grit vary in thickness from 2 to 20 ft., and are conglomeratic in places. Thus on Pinstane Hill, east-north-east of Little Clyde, is a bed of conglomerate which has been traced from the Clyde to the Tweed. It contains pebbles of Arenig volcanic rocks, quartzites, granite and mica-schist; the latter closely resemble certain rocks of the Eastern Highlands, and a detailed study of these and other pebbles may throw light on some of the problems of Highland geology. The shale bands interbedded with the grits yield *Crossopodia scotica* and *Myrianites tenuis.*

The coarse type of Queensberry Grits of the Moffat area extends as far south as Ettrick Pen, but in the region to the east and north-east the rocks are less massive and consist of flagstones, shales and greywackes. Beds of shale in Tima Water, Rankle Burn and at Deloraine in the Ettrick valley

have yielded *Monograptus crispus*, *M. exiguus* and *M. marri*. In the north-eastern part of the region from Selkirk and Melrose to Innerleithen there are numerous fossiliferous sections. At Coldshiels Loch, Lindean and other localities near Abbotsford the Birkhill Shales are succeeded by mudstones, shales and flagstones of the Abbotsford Flags, which yield numerous specimens of *Monograptus turriculatus*, *M. exiguus*, *M. marri* and *M. galaensis*. Dipping north-west the flags are followed by grits, greywackes with thin bands of shale (Buckholm or Queensberry Grits), well exposed at Buckholm Hill, Galashiels, Clovenfords and in Caddon Water. In places the shales have yielded *Monograptus exiguus*, *M. spiralis*, *M. crispus*, *Petalograptus altissimus* and *Retiolites geinitzianus*. The bedding planes of the shales are often covered with the tracks of *Crossopodia*, *Myrianites* and other annelids; these are especially abundant in the greenish-grey and red flaggy beds in the old ' slate ' quarries at Thornilee in the valley of the Tweed and at Greenhill south of Selkirk. Over this area, and particularly near the last locality, the isoclinal folding of the beds is well displayed, the dip of the folds being to the north-west.

Near Innerleithen excellent exposures have yielded fossils at several localities, especially in the Walker Burn about three miles up from its junction with the Tweed. In the Leithen Water opposite the manse, shales, which perhaps fall in the lower part of the Griestoniensis Zone, have yielded a rich fauna of graptolites, including *Monograptus crispus*, *M. exiguus*, *M. becki*, *M. marri*, *M. turriculatus* and *Petalograptus altissimus*; but the best locality is that of the Grieston quarry, where blue and grey shales with seams of limestone and calcareous ribs are exposed. The beds, which are inclined at high angles and are traversed by a porphyritic dyke, have yielded the zonal graptolite in association with *Monograptus spiralis*, *M. sedgwicki*, *M. vomerinus* and *Retiolites geinitzianus*. This locality is of historical interest, since the first graptolites figured from the region were obtained here by Nicol. In the Lauder district graptolites have been recorded from numerous sections, and many of the shale bands contain *Crossopodia*, *Protovirgularia* and *Myrianites*, but in the Easter Burn a conglomerate has yielded corals, crinoid stems and brachiopods, which, though in a poor state of preservation, nevertheless suggest equivalence with the Blackwood Beds of the Bargany Group of the Girvan area (p. 44).

Succeeding the Buckholm Grits are the greenish-grey shales with thin beds of greywackes collectively called the Hawick Rocks. They are typically developed south of the district between Ettrickbridgend and Selkirk. They are also intensely folded and throughout the area the axes of the folds are mainly vertical. With the exception of tracks of annelids, the beds are for the most part unfossiliferous, but fragments of *Ceratiocaris* have been found near Hawick. In the historical inlier at Allars Mill, near Jedburgh, vertical Hawick Rocks are overlain by horizontally bedded Upper Old Red Sandstone; it was this striking unconformity that attracted the attention of Hutton in the early days of geological science.

Between Hawick and Melrose the Gala rocks are unconformably overlain by the Upper Old Red Sandstone, but to the north-east of Lauder they extend to the sea by way of the Lammermuir Hills in a belt which is traversed by two valleys infilled with Upper Old Red Sandstone deposits. Along the coast between Cockburnspath and St. Abb's Head, the representatives

of the Queensberry Grits are well displayed, and in the cliffs massive greywackes, grits, flagstones and shales are constantly repeated by folding. Near Siccar Point grey and red shales yield fossils in abundance, and the following species have been recorded: *Monograptus barrandei*, *M. spiralis*, *M. crispus*, *M. exiguus*, *M. galaensis*, *M. nudus*, *M. pandus*, *M. marri* and *M. turriculatus*. Farther south the Hawick Rocks occupy the cliffs near Eyemouth.

South-west of Moffat, between the Nith and the Cree and westwards to the Mull of Galloway, a three-fold division is again discernible, flags, and shales of Abbotsford Flag type being followed by massive grits and greywackes of the Queensberry Grits and these in turn by Hawick Rocks. The first two subdivisions lie in synclinal folds which are frequently inverted between the anticlinals of Birkhill Shales. At Craigenputtock there is a conglomerate in the Queensberry Grits similar to that of Pinstane Hill; it contains pebbles of greywacke, grey and black shale, quartzite, quartz-schist, felsite, etc.

The Hawick Rocks occupy a broad strip of ground, extending from Castle Douglas to Gatehouse of Fleet. In this area the shales are more or less cleaved, and the prevalent trend of the cleavage-planes is about east-north-east to west-south-west. Excellent sections are exposed on the shore between the mouth of the Fleet and Meikle Ross and on the west side of Kirkcudbright Bay. So numerous are the folds on this part of the Solway that upwards of sixty anticlines and synclines have been mapped in a distance of one-and-a-half miles between Corseyard Point and Knockbrex. Typical Hawick Rocks occupy the headland of the Mull of Galloway.

Dailly Series. In the Girvan area the equivalents of the Gala Group dip at high angles towards the south-east and occupy a narrow belt extending from Penkill to the northern slope of Hadyard Hill, where they are faulted against the Lower Old Red Sandstone and Carboniferous Limestone Series on the south side of the Girvan valley. In the strip of Silurian rocks which extends from Hadyard Hill by Blair to Straiton, the highest members of the Llandovery are exposed. The rocks form part of the Dailly Series of Lapworth's classification, and in descending order the subdivisions are as follows:

Drumyork Group and Bargany Group 1,100 ft.	Green flagstones and shales, unfossiliferous Yellow, blue and grey flagstones and beds of shale (Blackwood Beds) Pale blue thick bedded flagstones and shales (Glenfoot Beds)
Penkill Group, 1,000 ft.	Cyrtograptus grayi mudstones and shales Protovirgularia grits Penkill flags and shales Purple shales and mudstones with *Crossopodia*, etc.

Penkill Group. Lithologically and palaeontologically the Crossopodia Shales at the base of this group resemble the ' slates ' of Thornilee Quarry on Tweedside, and are covered with annelid tracks, such as *Crossopodia scotica*, *Nemertites tenuis*, *Nereites sedgwicki* and *N. cambrensis*. Graptolites are also numerous in the dark seams, and include *Monograptus becki*, *M. exiguus*, *M. galaensis*, *Rastrites equidistans* and *Retiolites obesus*, which serve to establish their general equivalence with the lowest beds of the Gala Group of the Central Belt.

In the Penwhapple Glen section the Crossopodia Beds pass up into grits and flaggy greywackes, which, though not more than a few hundred feet thick, are perhaps the equivalents of part of the Queensberry Grits, and are equally poor in fossils. In the succeeding Cyrtograptus Mudstones there is an interesting alternation of graptolitic and shelly faunas. The beds are well displayed in the glen, 300 yds. north of the foot of the Penkill Burn. Among the prominent fossils, the following may be cited: *Cyrtograptus grayi*, *Monograptus concinnus*, *M. galaensis*, *M. nudus*, *M. marri*, *M. sedgwicki*, *Rastrites equidistans*, *Atrypa reticularis*, *Cyrtia exporrecta*, *Glassia obovata*, *Leptaena rhomboidalis*, *Orthis* (*Plectorthis*) *rustica*, *Sowerbyella penkillensis*, *Triplecia insularis*, *Lunulicardium elegans*, and *Orthoceras annulatum*.

Bargany and Drumyork Groups. Members of these groups outcrop in streams to the south of Bargany and on the northern slope of Hadyard Hill. In the Penwhapple section certain grey unfossiliferous shales and flagstones succeed the Cyrtograptus Mudstones and probably represent the Glenfoot Beds, which, in the Bargany Burn, include thin seams yielding *Monograptus acus* and *M. priodon*. In the higher Blackwood Beds an interesting fossiliferous horizon occurs, from which the Geological Survey has recorded: Plant remains, *Heliolites interstinctus*, *Palaeocyclus sp.*, *Discinocaris gigas*, *Encrinurus sp.*, *Orthis calligramma*, *O. polygramma*, *Pentamerus oblongus* and *Oriostoma discors*.

The Drumyork Flagstones, forming the highest subdivision of the Llandovery, outcrop in the Lady Burn, to the south of Drumyork Farm and towards the head of Glenmartin Burn, near Blair. They consist of unfossiliferous green and grey shales with bands of greywacke. The beds are inverted and dip to the south-east at a high angle.

Wenlock

As already mentioned on p. 5, the Southern Belt is occupied by rocks of Wenlock age. In the south-west they enter the region at Burrow Head, west of Wigtown Bay. Eastwards the formation appears on the shores of Kirkcudbright Bay and extends to the Nith as a narrow band of varying width. Along the Colvend shore of the Solway Firth the rocks are much altered in the neighbourhood of the Criffel granite. From the eastern margin of the Permian rocks of the Dumfries basin, Wenlock strata form an irregular belt of high ground, about six miles wide, ranging north-eastwards by Lockerbie to Mosspaul, thence to Stobs, near Hawick. Beyond these limits they appear as inliers on the northern slopes of the Cheviots. Throughout the area they dip to the south-east and appear to rest conformably on the Hawick Rocks; at the top they are unconformably overlain by the Upper Old Red Sandstone or Carboniferous beds.

The Wenlock rocks fall into two groups: the lower or Riccarton Group comprises conglomerates, greywackes, grits and shales, in all between 1,000 and 1,500 ft. thick. The higher or Raeberry Castle Group is thinner, and is estimated to be from 500 to 750 ft. thick. It includes green and olive shales with nodules of limestone, thin bedded greywackes with occasional bands of fossiliferous grit and conglomerate. Formerly, it was thought that rocks of Ludlow age were included in the higher beds, but there is no palaeontological

evidence to prove their presence. Indeed, it is highly probable that even the Wenlock division itself is not completely represented; the graptolite fauna indicates the presence of the Zones of *Cyrtograptus murchisoni* and *Monograptus riccartonensis*, and these are constantly repeated as a result of the prevalent isoclinal folding.

In the patch occupying the cliffs of Burrow Head dark seams associated with greywackes and shales of the Riccarton Group are highly fossiliferous. They are exposed on the shore about 400 yds. west of the headland, and have yielded the following graptolites: *Cyrtograptus murchisoni* (Fig. 4), *Monograptus flemingi*, *M. priodon*, *M. vomerinus* and *Retiolites geinitzianus* in a state of good preservation.

Both subdivisions are displayed in the coast-section east of Kirkcudbright Bay and onwards to White Port, where they are unconformably overlain by the basal conglomerate of the Carboniferous. The members of the higher group are well seen along the Raeberry cliffs. At Gipsy Point a band of conglomerate, which probably is on the same horizon as the highly fossiliferous band at Little Balmore Farm, near Abbey Burnfoot, has yielded '*Petraia*' *elongata*, *Favosites sp.*, casts of *Heliolites*, *Spirifer*, *Ptilodictya*, *Cornulites* and trilobite fragments. Near this locality limestone nodules interbedded with olive shales have yielded *Orthonota*, *Ctenodonta*, *Cucullaea*, *Murchisonia* and *Bellerophon trilobatus*. At Raeberry Point *Orthoceras etheridgei* occurs in flaggy shales associated with calcareous nodules.

In the district between Dumfries and Langholm the Riccarton Group is also represented by greywackes, flags and shales with dark brown seams containing, amongst other fossils, the characteristic species *Cyrtograptus murchisoni*. Higher up in the series *Monograptus riccartonensis* occurs, but as yet the Raeberry Castle beds have not been detected. Above Langholm Lodge at Wrae Hill and in the Ewes Water, however, a fossiliferous grit, similar to that at Gipsy Point, contains poorly preserved crinoids, corals and brachiopods.

Between Langholm and the River Jed three subdivisions have been recognized, but it is more than likely that the greenish-grey flaggy grits of the lowest subdivision are of Llandovery age, since beds in the middle subdivision yield *Cyrtograptus murchisoni*, *Monograptus priodon*, *M. vomerinus*, *Retiolites geinitzianus*. The crustaceans *Ceratiocaris papilio* and *Eurypterus sp.* have been found near Stobs Castle and in a streamlet at the head of Skelfhill Burn. The highest subdivision includes green mudstones and marly beds with nodular calcareous bands, and is equivalent to the Raeberry Castle Group.

In the Riccarton inlier rocks of the Riccarton Group occupy a long belt about two miles wide. To the north the strata are unconformably overlain by the Upper Old Red Sandstone, but the south-east and north-west boundaries of the inlier are defined by faults. The beds are nearly vertical and consist of thin bedded greywackes and shales. Some of the greywackes pass into conglomerates containing pebbles of quartz, mudstone and shale. Beds of shale outcrop at several localities near Riccarton, and yield *Cyrtograptus flaccidus*, *M. riccartonensis*, *M. priodon*, *Retiolites geinitzianus* and *Orthoceras subundulatum*. In the railway cutting west-north-west of Riccarton station the higher Raeberry Castle beds occupy a strip about 100 yds. broad.

On the northern slopes of the Cheviots one of the inliers is traversed by

Jed Water and Edgerston Burn. This inlier is bounded by rocks of Uppe Old Red Sandstone age. Smaller patches of Silurian appear here and there in the valleys where the Old Red Sandstone has been removed. Thus, they may be seen in the Willowford and Woodford Burns, in Riccarton Cleuch, in the bed of the Jed below Chesters, in the Carter Burn at Southdean and in the headwaters of the Jed near Dun Knowe. In all of these inliers the strata belong to the Riccartonensis Zone, and in most instances have yielded the characteristic graptolites.

In the Girvan district Wenlock rocks occupy a small area between the farm of Blair and Straiton village, north-west of the Southern Upland boundary fault. They are known as the Blair, Knockgardner and Straiton Beds, the highest members of the Dailly Series. On the south-east they are faulted against strata of Lower Old Red Sandstone age, while on the north-west they are overlain unconformably by the Upper Old Red Sandstone. Immediately to the north-east of Straiton, Wenlock rocks are faulted against Calciferous Sandstones.

The beds consist of greenish shales associated with bands of grit and greywacke conglomerates. Graptolites occur abundantly in thin seams of dark shale, and from a quarry near Blair the following species have been recorded: *Cyrtograptus sp.*, *Monograptus flemingi*, *M. priodon*, *M. riccartonensis*, *M. vomerinus* and *Retiolites geinitzianus*. The rocks are probably the equivalents of the Riccarton Group. In associated strata, species of *Favosites*, *Beyrichia*, *Eurypterus*, *Orthis* and *Orthoceras* are present.

East of Knockgardner some of the bands of grit are fossiliferous and among the common forms are: *Atrypa reticularis*, *Orthis* (*Dalmanella*) *elegantula*, *Sowerbyella transversalis*, *Calymene blumenbachi*, *Encrinurus punctatus*, *Phacops downingiae* and *Proetus stokesi*.

Additional References—Chapters II and III

continued from p. 33

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IV. OLD RED SANDSTONE

AFTER THE POST-SILURIAN movements had ceased part of the area was converted into a basin of deposition. This basin was termed Lake Cheviot by A. Geikie, and it was perhaps connected with the wider depression of the Midland Valley. The deposits fall into two subdivisions—a Lower Old Red Sandstone and an Upper Old Red Sandstone. The earliest sediments were laid down on the upturned edges of the older rocks, and consist of sandstones and conglomerates, the latter being deposited as torrential gravels. Great thicknesses of lava were poured out of volcanoes situated along the flanks of the high ground bordering the depressed area, and some of the lavas appear to have flowed into the lake and were later covered by sediment.

Further upheaval and denudation of the area is indicated by the marked unconformity at the base of the Upper Old Red Sandstone; and, during the subsidence which followed, sediments consisting mainly of conglomerates, sandstones and marls were spread over the Ordovician–Silurian rocks far beyond the boundary of the earlier basin. Towards the summit of the formation cornstones are numerous, and it is probable that this facies was continued into Carboniferous time in the north-eastern part of the area.

Lower Old Red Sandstone. As a result of pre-Upper Old Red Sandstone denudation, the Lower Old Red Sandstone occupies relatively small areas in the Girvan district, near Symington, West Linton and in the counties of Roxburgh and Berwick. In the latter area the rocks are exposed at Eyemouth, Reston, Coldingham and St. Abb's Head. They include red felspathic sandstones and conglomerates with occasional partings of red marl; the sediments were laid down in a freshwater lake and are associated with beds of coarse ash and flows of andesitic lava. The volcanic rocks are estimated to be at least 1,200 ft. thick. In the neighbourhood of Eyemouth several vents filled with agglomerate largely composed of andesitic fragments may be seen. An excellent example occupies the shore at Coldingham. The age of the sediments and lavas is determined by the occurrence of *Pterygotus*, and also by the fact that the beds are unconformably overlain by the Upper Old Red Sandstone.

In Roxburghshire the Lower Old Red is mainly represented by a great thickness of lavas which form part of the Cheviot Volcanic Series. The lava-flows fall into three groups: glassy pitchstone-like andesites, oligoclase-trachytes and augite-hypersthene-andesites; the rocks vary in colour, being red, brown, purple, grey or black, and are often vesicular. Agates are frequently found in the vesicles. While the flows are occasionally separated by beds of tuff, there are few intercalations of sediment. Isolated patches of coarse breccia occur, and probably indicate the sites of volcanic vents. On the Scottish side of the border such a patch has been mapped at Cocklawfoot at the head of Bowmont Water.

In addition to the lavas, numerous intrusions of Lower Old Red Sandstone age occur in the region, and the most striking feature of this igneous activity is the prevalence of a granodioritic or tonalitic magma over a wide

area. In the eastern part of the Uplands the intrusions occupy small areas at Priestlaw in the Lammermuirs, Cockburn Law and Stoneshiel Hill, near Duns. Smaller masses also occur on Broad Law in the Moorfoot Hills and Kirna Law, near Innerleithen. At Lamberton Beach there is a small knob of granodiorite or quartz-diorite; but the commonest type is a basic hornblende-biotite-granodiorite. At one time the Dirrington Laws and other masses near by were regarded as being of Lower Old Red Sandstone age, but evidence has now been brought forward to support a suggestion that they may be of Carboniferous age, especially those forming Blacksmill Hill and Kyleshill, near Duns (p. 66).

The more important intrusions, however, are the Criffel, Cairnsmore of Fleet and Loch Dee granitic masses in Galloway. The first two cut through Silurian strata, while the Loch Dee mass is intruded into Ordovician rocks along with smaller intrusions, such as Cairnsmore of Carsphairn, The Knipe, Afton Water and the granodiorite of Spango Water (Fig. 9).

Perhaps the most interesting of the three intrusions is the Loch Dee masf. This granite occupies an area extending from Loch Doon to Loch Dee, a distance of over eleven miles. It has a maximum width of six-and-a-hals miles and is surrounded by a girdle of altered sediments which form the Kells Range and Merrick. The plutonic rocks are of three main types: a basic rock (norite), an intermediate rock (tonalite) and an acid rock (granite). The granite forms a central ridge of hills, the highest of which is Mullwharchar. The rock is a biotite-granite, nearly white in colour and consists of quartz, biotite, orthoclase with microcline and oligoclase. Occasional crystals of orthoclase and microcline occur as phenocrysts. Muscovite and hornblende are sometimes present.

The tonalite and other closely allied rocks occupy the country on either side of the central ridge, and are generally grey in colour. The commonest variety consists of oligoclase, biotite and quartz; occasionally some orthoclase and hornblende are present. The smaller Burnhead mass lying to the east is a hornblende-tonalite. Frequently the tonalite contains xenoliths of highly altered sediments, and when tongues of the tonalitic mass penetrate the ring of sediments a distinct type of rock is formed; it is dark in colour, fine-grained and highly biotitic.

There are two principal masses of norite in the Loch Dee area, at the southern and north-western ends, and along the greater part of their boundaries they are in contact with Ordovician sediments. The norite is a dark-coloured medium to coarse rock composed of plagioclase, hypersthene (enstatite), augite, and in the more granitoid types quartz and orthoclase occur as interstitial matter. The marginal mingling of norite and tonalite magma has produced rocks of hybrid character.

The Criffel mass, which rises abruptly from the Solway and forms an elevated tract of land, extends from the river Nith to Bengairn, a distance of sixteen miles, and east of the river Urr has an average breadth of six miles. The longer axis of the mass runs in a north-east to south-west direction, thus coinciding with the strike of the Silurian rocks. The 'granite' is a moderately coarse grained grey rock composed of quartz, oligoclase, alkali feldspar, biotite and hornblende, with apatite, sphene and occasionally a pale-coloured augite as accessory minerals. The presence of

sphene is a feature of the Criffel mass. The rock is probably a tonalite, and in the Craignair quarry, near Dalbeattie, it contains numerous basic segregations. On the eastern slopes of Criffel the ' granite ' has a marked foliated character. These secondary structures may have been developed by dynamic action connected with earth-movements.

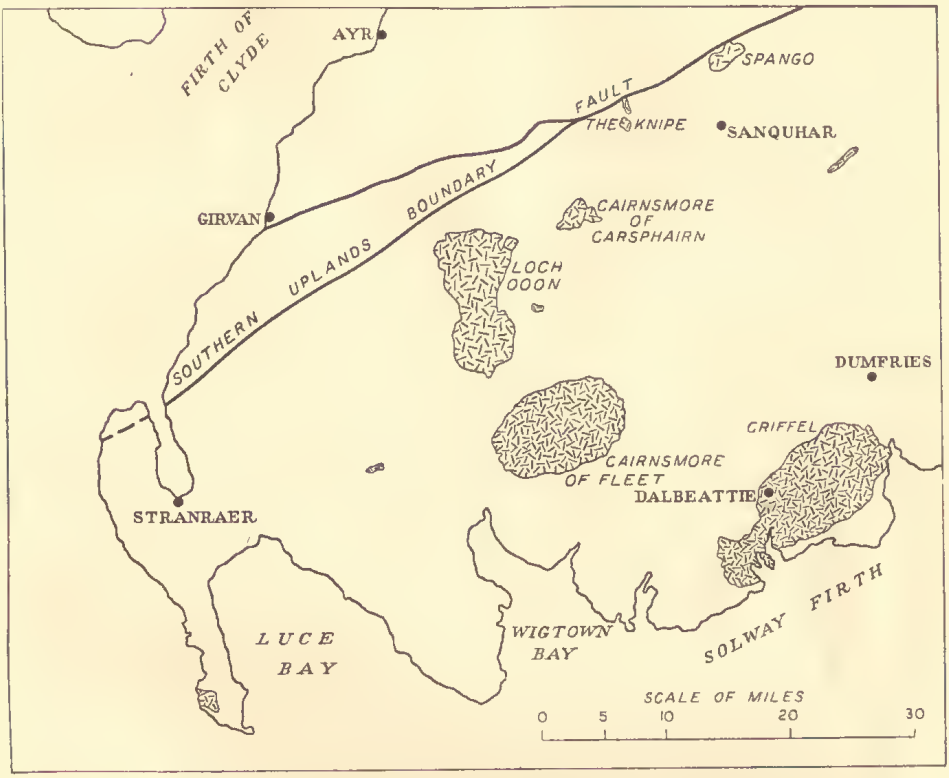

FIG. 9. *Map showing principal granite intrusions in South-West Scotland*

The granite which forms the oval-shaped mass of Cairnsmore of Fleet occupies an area lying between Criffel and Loch Dee masses. It is a more acid rock than either of the two last-named intrusions, and no rocks of tonalitic character have been observed. The granite is coarse-grained and grey in colour, having as its principal constituents oligoclase, biotite, alkali feldspar and quartz. Muscovite is sometimes present, and the rock then becomes a typical muscovite-biotite-granite. The accessory minerals are apatite, zircon and iron-ores; the occurrence of monazite has also been recorded

Several smaller intrusions of similar composition occur outside the area occupied by the large masses just described. The most prominent of these are: (1) the biotite-hornblende-granodiorite found in Spango Water on the south-east side of the Southern Uplands boundary fault, Afton Water and The Knipe; (2) the granite mass of Cairnsmore of Carsphairn; (3) the masses of Kirkcowan and Glenluce; and (4) the Portencorkrie mass of hornblende-granitite which occurs a few miles north-west of the Mull of Galloway

As already mentioned, one of the characteristic features of Lower Old Red igneous activity is the prevalence of a similar magma over a wide area. In the south-west, as in the north-east, all the plutonic rocks are intimately related, and the occurrence of the same types in widely separated localities suggests that they belong to the same petrological province. While the plutonic masses probably originated by differentiation of the contents of the same magma basin, Messrs. Gardiner and Reynolds believe that each of the three rock-types in Galloway represents a separate intrusion and have given the following reasons in support:

> " 1. Throughout a narrow band along much of the norite-tonalite boundary, and a wider one along the tonalite-granite boundary, the rock is of transitional or hybrid character.
>
> 2. The marginal part of the norite sometimes shows signs of alteration apparently by the tonalite.
>
> 3. Small areas of tonalite, presumably intrusions, occur within the limit of each mass of norite."

In Galloway a large number of dykes cut both the plutonic rocks and the surrounding sediments. As a rule they trend in a north-east to south-west direction. These minor intrusions fall into three groups: (1) acid rocks, such as aplites, granite porphyries, granophyres, microgranites and orthophyres; (2) porphyrites; and (3) diorites and lamprophyres. The majority of the dykes, however, consist of rocks to which the term porphyrite has been applied. They are, as the name implies, markedly porphyritic in structure, and in typical rocks of the group phenocrysts of plagioclase and hornblende are found in a compact ground-mass of similar minerals associated with quartz and alkali feldspar. The dyke rocks vary in colour from grey to red, and frequently show structural differences that are in all probability due to the conditions under which the magma consolidated. Some of the dykes are shattered by contemporaneous explosive action. The diorite-dykes are usually dark-coloured crystalline rocks essentially composed of hornblende and plagioclase feldspar.

In Wigtownshire many dykes cut Ordovician and Silurian strata. They are regarded as belonging to the dyke phase of the Galloway province. The rocks vary in composition from purely feldspathic varieties to lamprophyres, and include porphyrites, malchites, spessartites and kersantites.

The metamorphism resulting from the intrusion of molten igneous matter into the surrounding sedimentary rocks varies widely in amount and intensity. Thus, narrow dykes have effected little or no alteration in the adjacent strata, but around the margins of such large masses as those of Criffel, Loch Dee and Cairnsmore of Fleet great alteration has been produced: a broad ring of metamorphosed sediments surrounds the intrusions. In Galloway the altered rocks comprise grits, greywackes, grey and black shales, cherts, Arenig igneous rocks and dykes of Old Red Sandstone age, and the most abundant minerals resulting from the metamorphism are biotite, cordierite and garnet. The grits are characterized by the development of abundant brown biotite, while flaggy beds sometimes pass into a dark hornfels containing cordierite, or may in places become a mica schist. The black shales are frequently converted into chiastolite-slate, and graphite is often developed, while the beds of chert, especially those close to the intrusive mass, are completely recrystallized and form quartzite carrying masses of small garnets. The greatest degree of metamorphism, however,

is to be found in the xenoliths, and those in the tonalite sometimes contain corundum.

Upper Old Red Sandstone. The extent of the denudation which took place during the erosion interval within the formation is only partially reflected in the disconnected remnants of the Lower Old Red Sandstone. It is clear, however, that the older rocks of the Uplands were further denuded; deep valleys were eroded in Ordovician and Silurian strata and ran southwards into a broad depression which extended in a north-east to south-west direction across the region from the North Sea to the Solway Firth and possibly beyond it. Similar valleys which ran northwards into this hollow have also been traced in the Cheviot Hills. The Merse of Berwickshire and the Solway Firth form a mirror-image of this ancient and important structural feature. As will be shown later, a great extension of this depression took place in Carboniferous times as a result of further subsidence; but for the present purpose it is sufficient to say that the distribution of the Upper Old Red Sandstone deposits in the region reveals evidence of a drainage system which had been initiated probably on a floor of Lower Old Red sediments since the transverse valleys crossing the Lammermuir Hills cut the older rocks almost at right angles.

The Upper Old Red Sandstone occupies a tract of undulating country from near Greenlaw to a point south of Jedburgh. The outcrop in this area is of fairly uniform width, but at the southern end it suddenly narrows, and the formation continues as a faulted strip towards Riccarton and Langholm. Three miles west of the latter town another narrow belt of Upper Old Red Sandstone outcrops from beneath the Birrenswark lavas and extends south-westwards to the railway midway between Lockerbie and Ecclefechan, where it passes beneath a small patch of Permian before terminating against the west bank of the Water of Milk. On the west side of the Nith it is present in the Kirkbean district.

At the north-eastern end, near Lauder, conglomerates and sandstone extend as a narrow tongue up the Leader valley to New Channelkirk, and near Earnscleugh Farm they are cut by a monchiquite dyke with large porphyritic crystals of biotite. The main outcrop, however, swings to the north-east, and, forming the northern boundary of the Merse of Berwickshire, it runs to near Duns. Here it bifurcates, one strip trending eastwards past Chirnside to Mordington Church, near Berwick, and the other, going northwards through the Lammermuir Hills to Dunbar, gives rise to another narrow strip which runs in an easterly direction to Cockburnspath.

On the south-east side of the boundary fault near Fala and Gifford there are two patches of Upper Old Red Sandstone. The lowest member is a conglomerate, and consists of rolled fragments of greywacke. It is followed by red sandstones and red micaceous marls. South-east of Fala a more variegated set of sandstones occurs, and the coarser grits include small fragments of chert.

There is evidence that the Upper Old Red Sandstone originally covered a greater area than it at present occupies. It is probable, for instance, that much of the eastern part of the Lammermuir Hills was at one time overlain by Upper Old Red conglomerates and sandstones, since the conglomerate ascends to a height of 1,345 ft. on Monynut Edge, and several outliers occur

between St. Abb's Head and Berwick. The Eildon Hills, near Melrose, and several other outlying patches are found in the area between Melrose and Selkirk, while on Tudhope Hill, east of Mosspaul, a large block of Upper Old Red Sandstone is preserved in the agglomerate infilling a volcanic neck (Fig. 10).

The sections in the Jed, near Jedburgh, and at Siccar Point are of historical interest (Pl. I). They were visited and described by Hutton, and his studies of the highly folded Silurian rocks overlain by nearly horizontal sandstones and marls of the Upper Old Red Sandstone were the means of establishing some of the fundamental principles of geology.

In the Eyemouth district, the deposits rest with marked discordance on the Lower Old Red Sandstone, but in other areas they repose on an uneven floor of highly folded Silurian rocks. The lower part of the formation consists of reddish sandstones and conglomerates. The latter are largely made up of pebbles of grit, greywacke, felstones and other igneous rocks, and it is estimated that they attain a thickness of nearly 2,000 ft. near Duns. The sandstones are more or less composed of wind-rounded sand-grains for which a desert origin has been suggested, and the false-bedded character of some of them indicates a sand-dune mode of accumulation.

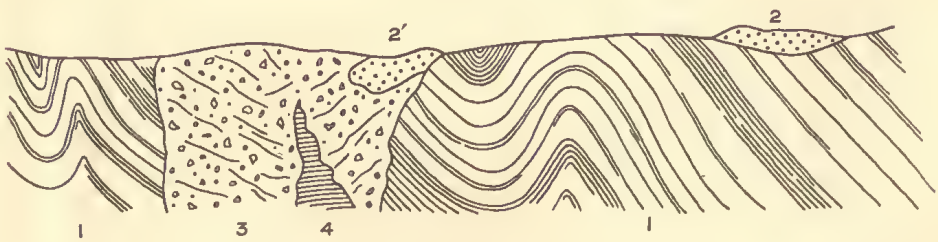

FIG. 10. *Diagram to show position of a mass of Upper Old Red Sandstone in vent near Tudhope Hill, east of Mosspaul*

1, Silurian; **2**, Outlier of Upper Old Red Sandstone; **2¹**, Large mass of this formation in vent; **3**, Agglomerate of the neck with basalt intrusion (**4**).

In the upper part the colour is usually less red, being characterized by the occurrence of irregular concretionary masses of cornstone, and on this account is often termed the Cornstone Group. Bands and lenticles of chert have been noted at Siccar Point, Roberts Linn and Riccarton. The fact that similar calcareous rocks are found in the Upper Old Red Sandstone and in the lower beds of the overlying Carboniferous makes it difficult to separate the two formations where decisive fossil evidence is lacking. Indeed, it is highly probable that rocks of Upper Old Red Sandstone facies were being deposited in the north-eastern part of the area while sediments of Carboniferous type were being laid down in the south-west.

In the lower part of the formation the following fishes have been found: *Bothriolepis obesa*, *B. leptocheira* and *Holoptychius nobilissimus*. The plant *Archaeopteris hibernica* has been recorded from a locality near Duns. The conditions under which the deposits accumulated are exemplified by the presence of sun cracks and rain-pitted surfaces.

Until recently no trace of any contemporaneous effusive volcanic rocks

had been found. Two lavas, however, interbedded with red marls in the Cornstone Group, have been recorded in a boring for water at Stonefold. near Greenlaw and have been referred to the Upper Old Red Sandstone. These are olivine-basalts of Dalmeny type, and are similar to those of the Kelso volcanic series at the base of the Carboniferous. It is possible that the lavas may represent an early effusion of the same series, but in view of the difficulties in separating the Upper Old Red Sandstone from the Carboniferous the question of age cannot be regarded as settled.

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V. LOWER CARBONIFEROUS

THE CONDITIONS UNDER which the earliest Carboniferous sediments were laid down differed but little from those which had prevailed during the deposition of the Cornstone Group; consequently, there is a gradual passage upwards from one formation into the other. The incoming of a brackish-water fauna indicates that the subsidence which originally gave rise to the Upper Old Red depression had continued, and with the retreat of the shore-lines the fresh water was replaced first by brackish water and later by the establishment of marine conditions. The sea invaded the region from the south-west at a time when a brackish-water type of deposit was being laid down in the north-east.

It would have been difficult to obtain a mappable horizon between the Upper Old Red Sandstone and the Carboniferous had the boundary depended solely on lithological differences of the sediments. The close of the Old Red Sandstone period, however, was heralded by great volcanic activity, and the lavas can be traced over a considerable part of the region, from beyond Greenlaw in Berwickshire to the west of the river Nith. They are of plateau types and have been arbitrarily taken as forming the base of the Carboniferous, although some of the lowest sheets are intercalated with sediments regarded as belonging to the Upper Old Red Sandstone; but, since the volcanic rocks appear to fall within one petrological province, it is probable that the boundary-line adopted has the same time-equivalence throughout the area.

The Lower Carboniferous rocks are continuous with those outcropping in Cumberland and Northumberland, and represent the Calciferous Sandstones and Carboniferous Limestones of the Scottish classification. From Abbey Head, which lies east of the entrance to Kirkcudbright Bay, they form a series of interesting patches fringing the Solway Firth eastwards to the Nith, and extending up the valley to Thornhill and Sanquhar. East of the river, Carboniferous rocks emerge from beneath Permian breccias and occupy a broad tract between Ecclefechan and Annan; thence, swinging round the basin filled with Triassic sediments, they extend north-eastwards up Liddesdale to near Riccarton. At the latter locality a narrow patch, let down by faults between the Silurian rocks of Arnton Fell, runs up Hermitage Water and extends to beyond Limekilnedge. The main outcrop, however, continues to Southdean and then passes into England. In the neighbourhood of Coldstream, Carboniferous rocks re-enter Scotland and occupy the Merse of Berwickshire, spreading over low-lying ground on the Scottish side of the Tweed from Kelso northwards to Duns and then eastwards towards Berwick. From the latter town a narrow faulted strip fringes the coast as far north as Burnmouth. Still farther to the north-west, beyond the area of Silurian rocks forming the eastern end of the Lammermuir Hills, a small basin of Lower Carboniferous strata occupies the coast between Cockburnspath and Dunbar. The occurrence of sandstone, fossiliferous limestone and shale in vent-agglomerates shows that the Calciferous Sandstone Series had a westward extension of more than ten miles beyond

its present boundary in Liddesdale. These patches and the outliers of Carboniferous rocks preserved in the Thornhill and Sanquhar basins lend support to the view that the Southern Uplands was largely, if not wholly, covered by the sea during the later part of the Lower Carboniferous period.

1. Eskdale and Liddesdale

The fullest development of Lower Carboniferous rocks is that found in the area traversed by the Esk and the Liddel, where the following subdivisions have been recognized:

		Thickness in feet
Carboniferous Limestone Series	Upper Limestones	300–400
	Kilnholm Coal Group	350
	Lower Limestones	500–700
Calciferous Series	Lawston Linn and Lewis Burn Coals	400–500
	Glencartholm Volcanic Group	300
	Fell Sandstone Group	400–600
	Cementstone Group (with marine limestones)	1,200–1,500
	Whita Sandstone	700
	Birrenswark Volcanic Group	

Birrenswark Volcanic Group. The Upper Old Red Sandstone, as in the Kelso district, is followed by flows of basaltic lavas which are regarded as forming a convenient base to the Carboniferous formation. The volcanic rocks are again referred to on p. 65, and no further reference need be made to them at this juncture.

Whita Sandstone. The lavas are succeeded by pinkish sandstones which pass upwards into yellowish gritty false-bedded sandstone with occasional lenticles of cornstone. In the higher reaches of Jed Water, bands of red sandy marl, indicating the prevalence of Old Red conditions, are present in the lower portion. The subdivision near Langholm is estimated to be 700 ft. thick, but towards the north-east it becomes thinner, and in the Meadow Cleuch Burn, which flows north from Carter Fell, there are perhaps not more than 250 ft. of sandstones.

Cementstone Group. In Eskdale and Liddesdale there is a remarkable development of this member of the Calciferous Sandstone Series. It is estimated to be from 1,200 to 1,500 ft. thick, and is well defined by its peculiar lithological characters. It includes variously coloured shales and mudstones of Ballagan type with bands of algal limestones, cementstones and marine limestones. The facies points to accumulation in a gulf mainly under estuarine conditions, but with periods during which the sea had access and covered the mud with deposits containing marine fossils.

In the Esk and in the lower part of Tarras Water the shales and mudstones dip in a southerly direction at an angle of 20°. In Liddesdale they spread over a broad tract owing to repetition by folding, and the best exposures are those found in the Harden, Larriston and Thorlieshope Burns. At Wormscleuch, west of Peel Fell and between Wheelrig Head and Carter Fell, there are several outcrops of algal limestone, a good section being exposed at the top of Meadow Cleuch.

Professor Garwood has established the following subdivisions in the group between the river Irthing in Cumberland and the Liddel Water. These are in descending order:

Cambeck Beds
Main Algal Series
Bewcastle Beds
Lynebank Beds

In Liddesdale the Lynebank Beds have not been recognized, and the earliest sediments present appear to belong to the overlying Bewcastle Beds. The lower part of the latter subdivision comprises sandy shales and mudstones obviously laid down in a lagoon. Among the common fossils are *Modiola lata*, *Spirorbis helicteres* and *Serpula advena* and ostracods. Higher up in the sequence, estuarine conditions gave way before an advance of the sea, as is indicated by the incoming of marine shells, such as *Camarotoechia proava*, *Aviculopecten geikiei*, *Edmondia josepha*, *Myalina verneuili*, *Nuculana attenuata*, *Protoschizodus axiniformis* and *Sanguinolites roxburghensis*; these are associated with crustaceans belonging to the genera *Crangopsis*, *Anthrapalaemon* and *Pseudogalathea*.

A remarkable feature of the Cementstone Group is the development of algal limestones. The remains of algae are first noticed in the Bewcastle Beds, but it is not until the Main Algal Series is reached that the algal growths become important as rock builders. These are typically developed in the Harden Burn, near Newcastleton, where the beds attain a thickness of about 180 ft. The lowest algal band contains *Ortonella* and *Aphralysia*, and in shaly mudstones a little higher in the succession the occurrence of lamellibranch shells invested with algae is of interest. The 'Main Reef' is a hard limestone, 7 in. thick, and displays the characteristic festoon-like growths of algae, amongst which *Ortonella tenuissima* is conspicuous. The associated rocks are also made up of algae, *Bevocastria* and *Girvanella* being common. The Bewcastle Beds and the Main Algal Series appear to fall in the Lower Syringothyris Zone, C_1.

In the strata overlying the Main Algal Series, marine forms become abundant in the limestones which are well exposed in the Larriston and Thorlieshope Burns. These rocks fall within the Cambeck Series, and among the numerous fossils cited from these localities the following are characteristic, and indicate equivalence, with beds placed in the Upper Syringothyris Zone, C_2: *Lithostrotion junceum* (first appearance), *Microcyathus cyclostoma*, *Syringopora ramulosa*, *Vaughania sp.*, *Poteriocrinus crassus*, *Athyris glabristria*, *Lingula scotica*, *Productus* (*Dictyoclostus*) *teres*, *Syringothyris cuspidata* mut. *exoleta*, *Myalina sublamellosa* and *Discitoceras sulcatus*.

Estuarine conditions are again in evidence immediately below the Fell Sandstones, and at Kersehopefoot there is a remarkable band of algal limestone, chiefly built up of *Garwoodia gregaria*, which has been traced for many miles along the Scottish and English borders. On the north side of Peel Fell a thin coal, about 10 in. thick, occurs near the top of the Cementstone Group; it is the lowest seam known in the district.

Fell Sandstone. This subdivision forms a unit that is easily traced throughout the area, and is thus of considerable stratigraphical importance. It consists of sandstones with thin intercalations of red and green marly clays and occasional cementstones, and varies in thickness from 400 to 600 ft.

The sandstones are siliceous and fine-grained, but certain layers are coarse and pebbly. On the summit of Carter Fell thin coal seams and fireclays are present, but the coals are of poor quality. In this district marine shells are also found on several levels, and grey clays crowded with ostracods, brachiopods and cephalopods occur close to the base of the sandstones at the old limekiln in Meadow Cleuch. Between Wheelrig Head and Carter Bar the Fell Sandstone appears to transgress the underlying Cementstone Series, and cut out the Cambeck Beds. The Fell Sandstone and the overlying Glencartholm Volcanic Group fall within the Upper Syringothyris Zone, C_2, but it is possible they also include the lower part of the Seminula Zone.

Glencartholm Volcanic Group. The occurrence of beds of tuff and a basic lava has led to the separate grouping of an interesting series of rocks under this title. The lava appears to be on the same horizon as those which rest on a conglomerate, north of Cockermouth, and the associated sediments are remarkable for the extraordinary richness of the flora and fauna contained in the shales, oil-shales and black cherts interbedded with the tuffs. The group is estimated to be about 300 ft. thick, and, although the horizon can be traced for some distance in the direction of strike, the highly fossiliferous shale has been found only at Glencartholm. The limited occurrence of the fossils may be due to the deposition of the shales in a creek which was shut off at intervals from the sea. Some of the characteristic fossils are given below, but the list represents only a small portion of the flora and fauna of the shales: *Bythotrephis plumosa*, *Spathulopteris decomposita*, *Asterocalamites scrobiculatus*, *Aviculoptecten eskdalensis*, *Leiopteria divisa*, *Posidonomya radiata*, *Anthrapalaemon etheridgei*, *Pseudogalathea macconochiei*, *Rostrocaris falcatus*, *Palaeosquilla parki*, *Palaeocaris scotica*, *Crangopsis eskdalensis*, *Eoscorpius glaber*, *Acanthodes nitidus*, *Canobius elegantulus* and eighteen other genera of fish. Some of the crustaceans have also been found in the Cementstone Group in Berwickshire.

Lawston Linn and Lewis Burn Coals. The group includes sandstones, shales, marine limestones and a number of thin seams of coal, and is from 400 to 500 ft. thick. One of the coals has been mined at Lawston Linn on the Liddel, but in Muir Burn, Tweeden Burn, and in the Esk, they are too thin to be of commercial value; on the English side of the Border, not far from Kersehopefoot, two of the seams were formerly worked. A limestone overlying the coal at Lawston Linn is from 6 to 8 ft. thick, and yields an assemblage of marine fossils, including species of *Clisiophyllum*, *Lithostrotion* and *Productus*, but the overlying shales and calcareous nodules are more highly fossiliferous and carry an abundant fauna. The group falls within the Seminula Zone, and is regarded as the equivalent of the Scremerston Series of North Northumberland; the coals are thus on the same horizon as the seams worked at Lewis Burn and Plashetts.

Lower Limestone Group. Lithologically, this group is similar to the underlying subdivision, and is of nearly the same thickness. The limestones, however, are more massive, and yield a rich fauna of corals and brachiopods; among these the following may be regarded as characteristic of the beds: *Chaetetes septosus*, *Dibunophyllum turbinatum*, *Lithostrotion junceum*, *L. portlocki*, *Productus* (*Gigantella*) *giganteus*, *Spirifer trigonalis*, *Camaratoechia pleurodon*, etc. The limestones are well seen in the Harelaw Hill quarry and

in the banks of the river Esk between Gilnockie Tower and Canonbie Mills, but perhaps the best sections are those exposed in Liddel Water at Penton Linns, where towards Penton bridge the beds are folded into a well-marked anticline (Pl. IVA). From one of the limestones associated with highly fossiliferous shales, the foraminifer *Saccamminopsis fusulinaformis* has been recorded.

It is highly probable that the group is equivalent to the Lower Limestone Group of the Midland Valley, but it may also include some of the limestones which occur in the higher part of the Calciferous Sandstone Series, and would thus fall within the Dibunophyllum Zone; perhaps the upper part of D_1 and the whole of D_2 are represented.

Kilnholm Coal Group. The limestones are followed by about 350 ft. of sandstones, shales and thin coals, thus indicating that a considerable shallowing of the sea had taken place. The coals are of little economic value, but form a useful stratigraphical horizon, since they are the probable equivalents of the Lickar Coals of Northumberland and the Limestone Coal Group of the Scottish coalfields. Thin seams of coal, probably on the same horizon, also appear in an anticlinal fold in the Esk between Gilnockie bridge and the foot of Byre Burn. It is obvious, however, that the valuable seams of this subdivision of the Scottish area have undergone considerable deterioration towards the south.

Upper Limestone Group. With the exception of a limestone, 3 ft. thick, and associated shales which outcrop in the Esk not far from the foot of Byre Burn, information concerning the beds has only been obtained from borings. The group is represented in the Rowanburnhead bore by 32 ft. of limestone and shale-bands.

2. West of the River Esk

In this area the Birrenswark lavas, which are well exposed at the type locality, dip southwards, and are followed by various members of the Calciferous Sandstone Series. At Kirtlebridge the limestones of the Lower Limestone Group are unconformably overlain by the Trias, and have yielded, in addition to characteristic corals and brachiopods, species of *Orionastraea*, a rare fossil in Scotland. The limestones are again seen beyond the river Annan at Kelhead and Clarencefield. At the former locality there are three beds of reddened limestone, amounting in all to 30 ft. in thickness. A bed of shale below the upper limestone contains rhizomes of *Stigmaria* in position of growth. Fossils are scarce in the shales, but the limestones have yielded the following corals: *Lonsdaleia floriformis laticlavia*, *Lithostrotion irregulare*, *L. junceum* and *Syringopora*. These are associated with the variant of *Productus* (*Gigantella*) *giganteus*, which is characteristic of the Hurlet Limestone of the Central Coalfield.

West of Ecclefechan the lavas and the lower part of the Cementstone Group are terminated by a fault which brings them against the Wenlock, but between Annan and Caerlaverock the higher beds pass under the alluvium of the Solway.

3. The Solway Firth

Along the shore of the Solway, Lower Carboniferous strata are found at intervals between the mouth of the Nith and White Port, a few miles east of Kirkcudbright Bay. All the rocks fall within the Calciferous Sandstone Series. The largest patch in which a fairly complete succession is present occupies an area near Arbigland, and is well exposed on the coast between Southerness and Hogus Point. The limestones of Arbigland have long been famous for the abundance and beautiful preservation of their fossil corals.

The Birrenswark lavas succeed the Upper Old Red Sandstone in the Kirkbean Glen, and in the Ladyland Burn they in turn are followed by sandstones and shales of the Cementstone Group, which dip to the north-east at an angle of 20°. The lower part of the lavas is slaggy and amygdaloidal, and where the rock has been fissured the crevices are filled with baked sandstone.

On the shore there is an excellent section in which the equivalents of the higher part of the Cementstone Group, the Fell Sandstone and a portion of the overlying marine beds of Liddesdale are represented. The strata, however, are greatly folded and faulted, and estimates of thickness are difficult to make, but the rocks may be grouped in descending order as follows:

Lithostrotion limestones of Arbigland Bay
Sandstones and shales with numerous limestones
Thirlstane Sandstone
Sandstones and shales with marine bands and cementstones

The fossiliferous character of the beds simplifies the task of correlation with the Liddesdale succession. The marine bands below the Thirlstane Sandstone yield a fauna identical with that which characterizes the upper part of the Cambeck Series at Larriston and Thorlieshope. Among the fossils from Southerness typical examples of *Syringothyris cuspidata* mut. *exoleta* are especially noteworthy, and the layer of *Garwoodia gregaria* here found to pass beneath the Thirlstane Sandstone is identical with the algal layer which underlies the Fell Sandstone of Liddesdale.

The overlying coralline limestones are perhaps equivalent to some of the lower beds in the Lawston Linn and Lewis Burn Coal Group. They occupy a symmetrical basin in Arbigland Bay, and are remarkable for the abundance of well preserved species of *Lithostrotion*, such as *L. irregulare*, *L. junceum* and *L. portlocki* in association with *Chaetetes septosus* and numerous molluscan remains.

Farther west, the Birrenswark lavas disappear, and the lower part of the Cementstone Group is represented by coarse sandstones and conglomerates which clearly point to the proximity of the Carboniferous shore-line. The pebbles found in the conglomerates include greywackes and felsites, and have obviously been derived from the metamorphosed Silurian rocks; but here and there, as at Aird's Point, Barlocco Heugh and in the patch east of the Urr Water, boulders of granite are conspicuous, thus indicating that the granite masses of Criffel were exposed and eroded in Carboniferous time. In places the conglomerates rest unconformably on the Silurian, but more frequently they are faulted against the older rocks.

In the narrow patch which occupies the coast for a distance of seven miles between Aird's Point and Abbey Burnfoot, the Carboniferous sandstones and conglomerates are faulted against altered Silurian rocks, but from Barlocco westwards they rest unconformably on the greywackes. On the east side of Port Mary Bay the conglomerates are traversed by veins of barytes. This mineral is also found in a vein cutting a sandstone north-east of Lochanling, and nearby is a remarkable quartz lode, 21 ft. broad, also traversing sandstones. In the higher beds opposite Rerwick Park several bands of red-stained limestone occur interbedded with layers of red conglomerate, and at Orroland the limestones contain numerous fossils, including *Lithostrotion*, *Syringopora* and *Productus*; they perhaps correspond in position to the Cambeck Series.

The most westerly patch at White Port occupies a somewhat broader area than the last named. Here, again, the Carboniferous beds include coarse concretionary sandstones, grits and conglomerates. The basal conglomerate rests unconformably on the Silurian, and is largely made up of pebbles of greywackes, porphyrites and felstones.

4. Berwickshire

In this area flows of olivine-basalt occur at the base of the Cementstone Group, and can be traced from Duns southwards to Greenlaw, and thence across the Tweed west of Kelso to the north flank of the Cheviots. The lavas are known as the Kelso Traps and are of the same petrological character as those of Birrenswark.

Close above the lavas lies the well-known Carham Stone, a cherty magnesian limestone of chemical origin, which was deposited in thin layers in pools subject to desiccation. It is thought that the lime-content of these waters had been increased by showers of volcanic dust during the final stages of the Kelso eruptions.

The overlying sediments are of Ballagan type, and consist of variously coloured shales with many bands of sandstone, seams of impure limestone and cementstone with partings of gypsum. The total thickness of the group is estimated to be from 2,500 to 3,000 ft. thick. The beds represent estuarine deposits of mud, silt and sand which had been deposited on flats at or near sea-level; the numerous sun-cracks and rain-pittings on the surface of the shales are evidence of frequent exposure during accumulation, but the presence of gypsum and rock salt indicates that the sea must have had occasional access. No trace of marine bands similar to those in Liddesdale have been found.

The lowest beds are well seen along the course of the Whiteadder and in tributary streams between Foulden and Mordington. Near Foulden an important section is exposed in the Crooked Burn, below Newton Farm, where sandy shales and mudstones contain numerous fish remains. The beds lie close to the base of the group, and have yielded *Acanthodes ovensi*, *Gyracanthus sp.*, *Callopristodus pectinatus*, *Strepsodus* cf. *sulcidens*, *S. striatulus*, *Fouldenia ottadinica*, *Carboveles ovensi*, *Aetheretmon valentiacum* and *Strepheoschema fouldenensis*. Associated with the fish are arthropods,

lamellibranchs and plants. The arthropods include *Glyptoscorpius caledonicus*, *Tealliocaris sp.* and *Crangopsis eskdalensis*.

Fairly high up in the Cementstone Group many plant-petrifactions showing well preserved micro-structure have been found at Lennal Braes, about two miles from Coldstream Bridge on the Scottish side of the Tweed. From this locality Witham obtained many of the species described by him in *Fossil Vegetables*.

The Cementstone Group again occurs in a narrow strip fringing the coast from Lamberton northwards to Burnmouth. The shales are faulted against Silurian rocks along their western boundary, and are nearly vertical in proximity to the fault. At Burnmouth the group includes reddish, grey and white sandstones with interbedded greenish marly shales and thin bands of impure limestones containing *Modiola* and other lamellibranchs; some of the beds may be equivalent to the Fell Sandstone.

At Hilton Bay and Lamberton there is a band of brownish-yellow limestone, 1–3 ft. thick, known as the Lamberton Limestone. It is highly fossiliferous, and yields *Lithostrotion junceum*, *Chaetetes depressus*, *Productus* (*Gigantella*) *giganteus* and other species in abundance. The limestone, which probably represents the Dun Limestone of Northumberland, is in two layers, and is associated with two seams of coal; these, however, are of little value.

5. Area South-east of Dunbar

From Cove, near Cockburnspath, to within a mile of Dunbar an interesting succession of Lower Carboniferous rocks is exposed along the coast. The area occupied by the outcrop is about two miles wide, the inland boundary being determined by the Innerwick fault. The beds fall within the Calciferous Sandstone Series and the Lower Limestone Group of Scotland.

Calciferous Sandstone Series. Here the boundary between the Upper Old Red Sandstone and Carboniferous is well defined. The base is taken below a bed of coarse breccia largely made up of fragments of cementstone, and is overlain by a calcareous rock crowded with plant remains, ostracods and lamellibranchs. Then follows the Horse Roads Sandstone, a false-bedded greyish rock, 140 ft. thick, containing large concretions near top (Fig. 11).

The Cementstone Group is brought by the Cove fault against the Kip Carle Sandstone, a coarse false-bedded rock, which is regarded as the equivalent of the Fell Sandstone. It contains numerous plant remains, and is succeeded by 85 ft. of sandy and shaly strata in which six thin coals of poor quality are interbedded. Gunn suggested that this carbonaceous group corresponds to part of the Scremerston Coal Series. Between the top of the carbonaceous beds and the Bilsdean Sandstone there are over 500 ft. of strata, in which two prominent false-bedded sandstones occur, the Heathery Heugh and Cove Harbour Sandstones. In the succession two limestones are also present, the Cove Lower Limestone, 15 ft. thick, with crinoids, brachiopods and lamellibranchs, and the Cove Upper Limestone, containing *Productus* and *Spirifer*. These limestones probably correspond

to the Dun and Woodend Limestones of the Northumberland sequence, and the oil-shale which overlies the Cove Harbour Sandstone may be equivalent to a similar oil-shale lying between the Woodend and Oxford Limestones of the North of England. On what appears to be a higher position there is an impure shaly limestone about 7 ft. thick associated with a 10-in. coal and sandstones containing thin shale seams crowded with plants, *Telangium affine*, etc. It is known as the Linkhead Limestone and is characterized by an abundance of *Lithostrotion junceum* and other fossil remains. Gunn considered this limestone to represent the Oxford Limestone (a correlation with which the writer is in agreement), but it has been suggested that the Linkhead Limestone should correspond in position with the Cove Upper Limestone, although the two beds differ in lithology and in fauna.

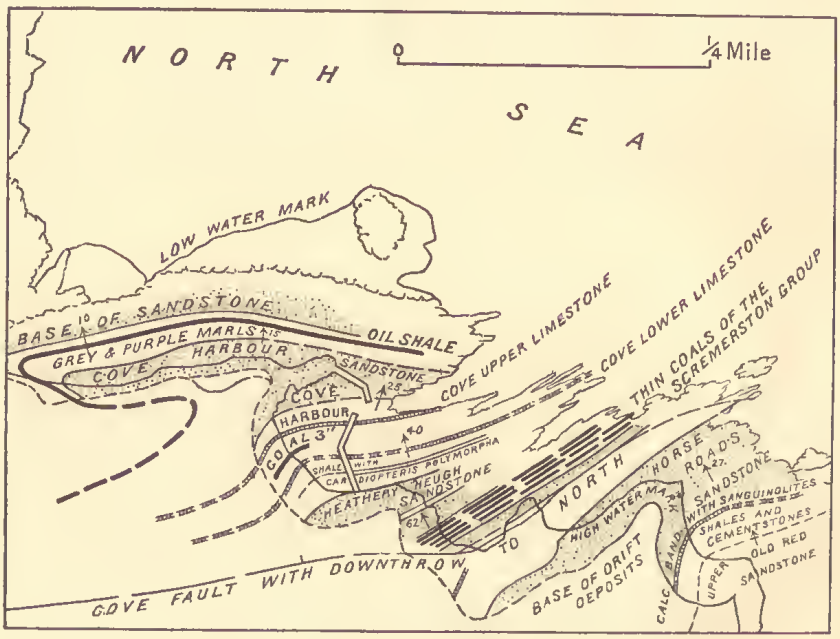

FIG. 11. *Map of coast near Cove Harbour*

The highest beds of the Calciferous Sandstone Series consist mainly of arenaceous strata, and are well exposed on the shore at Thorntonloch where they are faulted against the basal members of the Carboniferous Limestone Series. A ferruginous bed near the top contains abundant remains of *Nuculana attenuata* and other lamellibranchs.

Carboniferous Limestone Series. With the exception of some 70 ft. of strata at the top, the beds of this subdivision fall within the Lower Limestone Group of Scotland. The series is over 300 ft. thick and includes a number of thin limestones, each of which is separated by beds of sandstone and shale of variable thickness. The succession is as follows, in descending order:

	Ft.
Barness East Limestone	2–6
Strata, mainly sandstones	50
Dryburn Foot Limestone	about 2
Sandstone and shale	10
Chapel Point Limestone	about 10
Sandstone, fireclay and shale with coal smut	103
Skateraw Upper Limestone	1–2
Black shale	about 5
Skateraw Middle Limestone	16–18
Coal (6-in.), shale and fireclay, etc.	8½
Skateraw Lower Limestone	2–4
Sandstone and shale	23
Long Craig Upper Limestone	18
Shale with thin coal in places	5
Long Craig Middle Limestone	3–6
Sandstone and shale	25
Long Craig Lower Limestone and shales	39

The limestones and associated beds occupy the coast for about four miles, and are disposed in two synclinal folds, the small northerly basin being separated by a fault in the line of which there is a broad dolerite dyke.

The Long Craig Lower Limestone is taken as the base of the Lower Limestone Group, but it is possible that it may represent the highest limestone of the Calciferous Sandstone Series. The Long Craig Middle Limestone is a whitish rock, rich in corals, such as *Lithostrotion junceum*. The top of the bed is indented by numerous basin-shaped hollows, which contain the underclay of the overlying coal. Stigmarian rhizomes and rootlets are abundant in the clay. The limestone itself is regarded as the equivalent of the Eelwell of the Northumberland succession. The Upper Long Craig Limestone is also cream-coloured; north of the lighthouse it is crowded with corals, and about 4 ft. from the top there is a band characterized by a species of *Koninckophyllum* associated with *Aulophyllum fungites*, *Dibunophyllum muirheadi*, *Lithostrotion junceum*, *Zaphrentis enniskilleni*, etc.

The three Skateraw Limestones are well seen on the shore at Skateraw. The lowest is dark in colour, and along the bottom of the bed is a prominent layer of shells of *Productus* (*Gigantella*) *giganteus*. The middle limestone is of a similar hue, and near the top is a band, about 2 ft. thick, crowded with *Saccamminopsis* (*Saccammina*) *fusulinaformis*. It was correlated by Bennie, and later by Gunn, with the Acre Limestone of Northumberland. The equivalence of these limestones is further strengthened by the occurrence of *Cyathaxonia cornu* and a mutation of *Caninia cornucopiae* in the overlying shales. These coral species are confined to this horizon in Midlothian and Northumberland. The Upper Skateraw Limestone is ferruginous and crinoidal.

The Chapel Point Limestone is sandy, and contains small lenticles of chert with *Saccamminopsis fusulinaformis* and *Endothyra*. North-west of Catcraig the top layer is rich in Spirifers, crinoids, spines of *Archaeocidaris* and the curious fossil *Spirophyton cauda-galli*. This calcareous horizon may represent the Low Dean or Sandbanks Limestone of Northumberland. The succeeding Dryburnfoot Limestone is also sandy, and contains plants and crinoid remains.

The highest limestone of the group is known as the Barness East Limestone. It rests on a hard sandstone full of worm-tubes. Throughout its greater thickness the bed is very sandy, but the upper layer is more calcareous

and yields specimens of *Lonsdaleia* of *laticlavia*-type. The limestone probably represents the Great or Dryburn Limestone of Northumberland, and it and the two underlying beds clearly show the lithological change which sets in when their equivalents in the North of England succession are traced northwards into Scotland.

Limestone Coal Group. The Barness Limestone is followed by some 70 ft. of strata which include sandstone, shale and a thin coal. They represent the lower portion of this important group of the Central Coalfield.

6. Thornhill and Sanquhar Outliers

By reason of their situation on the Southern Uplands the patches of Lower Carboniferous strata preserved in the valley of the Nith are of unusual interest. The sections reveal that the Carboniferous rocks were laid down on a slowly subsiding area, and since they show a progressive overlap of the beds northwards, the sea appears to have invaded the region from the south. In view of this it is likely that Carboniferous rocks are present beneath the Permian in the Dumfries and Lockerbie basins as at Thornhill. Further, it is certain that much of the Southern Uplands was submerged before the close of Lower Carboniferous time.

In the Thornhill basin Lower Carboniferous rocks are exposed in four small areas at the southern end, the best sections being at Closeburn and Barjarg. The succession at the old quarries at Closeburn is as follows:

	Ft.
Red well-bedded sandstones with purple and red mottled shale and fireclay	40
Red dolomitic limestone (Hurlet?)	14
Red sandstone and clays with plant remains	18
Red fossiliferous limestone with *Productus giganteus*, etc.	18

The lower bed of limestone rests directly on Silurian greywackes. It is equivalent to the *Productus giganteus* limestone of Coalburn and Douglas in Lanarkshire, and therefore marks the top of the Calciferous Sandstone Series. The limestone is highly fossiliferous, and has yielded the following characteristic fossils: *Lonsdaleia* cf. *floriformis*, *Zaphrentis sp.*, *Productus* (*Gigantella*) *giganteus*, *P. productus*, *P.* (*Dictyoclostus*) *pugilis*, *Phillipsia eichwaldi* and the palatal teeth of *Psammodus*. The upper limestone is dolomitic and, although it has yielded no fossils, it may be regarded as the equivalent of the Hurlet Limestone of the Central Coalfield.

The next section is that found in the Enterkin Burn at the northern end of the basin, where calcareous sandstones, a few feet thick, intervene between the overlying Upper Carboniferous rocks and the highly folded Ordovician greywackes. The beds are very fossiliferous, and the following shells are a few of the common forms: *Buxtonia scabricula*, *Productus* (*Dictyoclostus*) *pugilis*, *Camarotoechia pleurodon*, *Spirifer bisulcatus*, *Aviculopecten interstitialis* and *Bucanopsis decussatus*. The fauna is characteristic of the Lower Limestone Group, and the beds may be equivalent to the Hosie Limestones of the Central Coalfield.

In the Sanquhar basin still higher beds of Lower Carboniferous age occur in a number of outliers at the eastern end of the coalfield. In the

Loch Burn a narrow strip of shales with thin bands of limestone is exposed, and is overlain by Coal Measures. It is highly probable that Lower Carboniferous deposits continue beneath the coalfield, since at the western end they again outcrop in the Polhote Burn, where some 20 feet of shales with *Sphenopteris taitiana* and *Sphenophyllum tenerrimum* rest on greywackes and are overlain by Upper Carboniferous sandstones. Numerous fossils have been collected from the various outcrops and include the following plants and shells: *Adiantites* cf. *tenuifolius*, *Avonia youngiana*, *Productus* (*Gigantella*) cf. *latissimus*, *Myalina flemingi*, *Palaeolima simplex*, etc. The beds are equivalent to a portion of the Upper Limestone Group.

Volcanic Rocks of Lower Carboniferous Age. As already mentioned, there is a great development of basaltic lavas at the base of the Carboniferous in Berwickshire, Roxburghshire and Dumfriesshire. The rocks are olivine-basalts of plateau type, and although some of the earlier flows are intercalated in sediments of Upper Old Red Sandstone facies, the outpouring of the lavas on a grand scale took place at the beginning of Carboniferous time. In the overlying Cementstone Group the discharge of lava and ashes was confined to volcanoes of puy type; by the close of Calciferous Sandstone time volcanic activity had ceased. The following types of rock have been recognized in the lavas and their associated plugs, dykes and sills:

Macroporphyritic Olivine-basalts (*with many large phenocrysts*)

Markle Type: with phenocrysts of labradorite-feldspar and olivine
Dunsapie Type: with phenocrysts of labradorite-feldspar, olivine and augite
Craiglockhart Type: with phenocrysts of olivine and augite

Microporphyritic Olivine-basalts (*with many small phenocrysts*)

Jedburgh Type: with phenocrysts of labradorite-feldspar and olivine
Dalmeny Type: with phenocrysts of olivine and sometimes sporadic labradorite and augite
Hillhouse Type: with phenocrysts of olivine and sometimes of augite

The main groundmass constituents are labradorite, augite and iron ore in all cases except the Hillhouse Type, in which they are augite, iron ore and a little labradorite, with analcite or glass. Parallel arrangement of the feldspar laths is characteristic of the Jedburgh type.*

In Berwickshire the lavas are known as the Kelso Traps, and attain their greatest development about Stichel and Smailholm (Pl. IIIB). It is evident that they flowed from numerous orifices, and the group of large agglomerate necks found between Melrose and Selkirk may perhaps mark the sites of the vents.

The equivalents of these lavas are found in Roxburghshire and Dumfriesshire. The main outcrop extends from Dinley on the Hermitage Water, by Langholm and Birrenswark to the west bank of the Nith, where it dies out in the Kirkbean district. The lavas are faulted against the Silurian inlier of Arnton Fell and stretch from Castleton Manse by Riccarton, disappearing near the junction of Caldron Burn and Liddel Water. They attain their greatest development in the Birrenswark area. The lower flows are associated with the cornstones at the top of the Upper Old Red Sandstone, as in Berwickshire, and consist of slaggy amygdaloidal olivine-basalts. The prevalent rock is allied to the Jedburgh type, but grades locally into the more basic Dunsapie type. Intrusions of a black porphyritic basalt on Pike

*For further details *see* British Regional Geology " The Midland Valley of Scotland."

Fell and Arkleton Hill appear to mark the sites of vents from which the lavas were erupted. A third vent, on Coombs Fell, consists of a plug of fine-grained olivine-basalt intermediate between the Dalmeny and Hillhouse types. The plug rises through a mottled red and green agglomerate.

Higher in the Cementstone Group, patches of lava mainly of Markle type occur at Foalfootstone, Lumsden Law, Catscleugh and Carter Fell, and they appear to have flowed from numerous vents of puy type in the neighbourhood. The sites of many of these puys are known (Fig. 12), and in Teviotdale three kinds of vents are distinguished; these are as follows:

1. Basalt and agglomerate necks of Ruberslaw, Black Law and Lanton Hill
2. Basaltic necks of Dunion Hill and Fatlips Crags
3. Agglomerate necks of Minto Hills, Troner Hill and Ancrum Craig

The basaltic rocks forming the plugs are of Jedburgh type.

Still higher in the Cementstone Group are the lavas on the summit of Windburgh Hill; these are Markle type of basalts which are regarded as having been extruded from the vents of Scaw Law and Maiden Paps, now filled with coarse non-porphyritic lavas of Dalmeny type.

Many small necks of tuff and agglomerate cut the Cementstone Group which floors the country between Hermitage Water and Langholm. Tinnis Hill neck, which is the largest of these, is of oval shape and lies between Newcastleton and Langholm. The tuff is fine-grained and pink in colour, and is pierced by a plug of non-porphyritic basaltic rock of Jedburgh type, but as Lady McRobert points out, the preponderance of augite phenocrysts indicates a passage towards a rock of Dalmeny type. It is probable that these necks formed the vents from which the Glencartholm beds of tuff and lava were erupted. It has already been mentioned (p. 57) that the basic lava of Glencartholm is equivalent to lavas of S_1 age at Cockermouth in Cumberland.

Of still younger date are the alkaline and acid rocks which appear to represent a late phase of vulcanicity, and they probably correspond to the trachytic lavas and intrusions of Garleton Hills and similar intrusions in the Campsie and Renfrewshire Hills. The chief types of rock represented are porphyritic and non-porphyritic quartz-trachytes, sanidine-trachyte, sanidine-porphyry, riebeckite-bearing felsite, quartz-porphyry and basalt. The sites of some of the vents are marked by necks filled with agglomerate which, in some cases, is pierced by a plug of basalt.

In Berwickshire four intrusions of felsite occur in conglomerates and sandstones of Upper Old Red Sandstone age, and form the hills of Dirrington Laws, Blacksmill Hill and Kyleshill. In the first three masses the intrusion is a riebeckite-bearing rock which Irving finds to be identical with the quartz-riebeckite-felsite of Wester Hill of Eildon (p. 68) and may be a laccolite of the same age. On Kyleshill, however, the rock is different; it consists of phenocrysts of feldspar embedded in an orthophyric groundmass of orthoclase, quartz and haematite. It appears to be pierced by a dark bluish rock resembling andesite, but the relations of the two rocks are obscure. Although formerly regarded as intrusions of Old Red Sandstone age, there seems little doubt that they are of the same date as those of the Eildon Hills presently to be described.

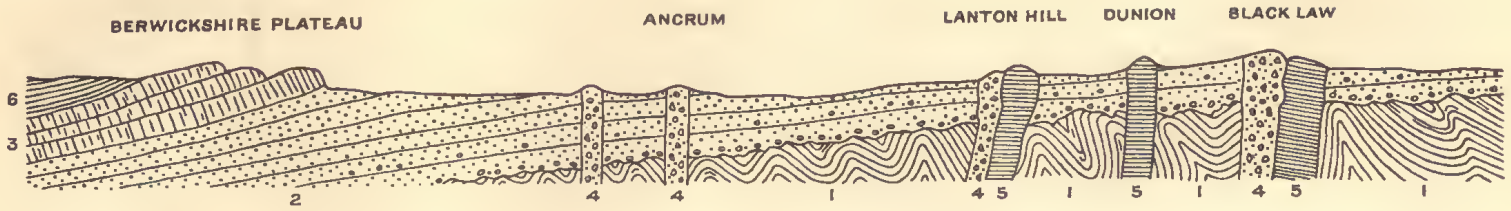

FIG. 12. *Section across Southern Berwickshire to show the relation of the volcanic plateau to the vents lying south from it*

1, Silurian; **2,** Upper Old Red Sandstone; **3,** The volcanic plateau; **4,** Agglomerate and tuff of the vents; **5,** Intrusive basalt and dolerite; **6,** Lower Carboniferous.

In the neighbourhood of Melrose the volcanic rocks may be grouped as follows:

Laccolites and sills	of White Hill, Black Hill, Bemerside, Eildon Hills, Bowden Moor and Whitelaw Hill
Dyke rocks	Several between Melrose and Selkirk: mostly trending north-east
Necks	Several; of which the principal is Chiefswood, near Melrose

The most conspicuous intrusive rocks are those of the Eildon Hills (Pl. IIA). They are regarded as representing the denuded remains of a composite laccolite, and the intrusions have been made sheet by sheet, giving rise to the appearance of stratification. The rock of the North Hill differs from that of the Mid or Wester Hills. It consists of porphyritic and non-porphyritic varieties of sanidine-trachyte, and although similar porphyritic trachyte is found in the other hills, these for the greater part are formed of a riebeckite-felsite, disposed in two layers (Fig. 13). On the south-west face of the Wester Hill the upper layer shows magnificent columnar structures. The summit of Mid Hill is occupied by an orthophyric riebeckite-trachyte showing contorted fluxion. To the west of the mass is an augite-olivine-trachyte, which closely resembles rocks from Traprain Law and the Bass Rock in East Lothian.

The dyke rocks include trachytes, banded felsites and quartz-porphyries, and their general trend is parallel to the strike of the Silurian.

The oval-shaped mass forming the Chiefswood neck is about one and three-quarter miles long and three-quarters of a mile broad. It consists of angular fragments of Silurian and Old Red Sandstone mingled with bits of quartz-porphyry, trachyte and olivine-basalt, and is pierced by a dyke of quartz-porphyry. The Little Hill neck is a plug of basalt consisting of plagioclase zoned with orthoclase and olivine in small granules. It shows fluxion structure.

In Teviotdale alkaline and acid rocks, many of them identical in appearance with those of the Eildon Hills, occur as plugs and dykes. The rocks form the summits of peaks, such as Skelfhill Pen, Leap Hill, Greatmoor, etc., and the chief types represented are porphyritic and non-porphyritic sanidine-trachytes, phonolites and phonolitic trachytes (Clinkstones). A micro-porphyritic riebeckite-trachyte is found on a ridge north-east of the Craig in Skelfhill Burn.

The broad dyke-like mass of riebeckite-trachyte on the summit of Skelfhill Pen is connected with Piketlaw Hill by a series of dykes of phonolitic trachyte consisting of sanidine, aegirine-augite, acmite, riebeckite, nepheline and magnetite. One of the dykes is identical with the phonolite of Fintry in the Campsie Hills.

The necks in this district are composed of an agglomerate of grits, shales, greywackes and angular fragments of trachyte, and are often pierced by intrusions. One on Tudhope Hill, which lies to the east of Mosspaul, is of special interest on account of the large block of Old Red Sandstone which had evidently fallen into the vent (Fig. 10). This neck is pierced by basalts of Craiglockhart type at the southern end; at the northern edge the agglomerate is penetrated by a plug of trachyte, closely resembling a sediment in appearance but mineralogically identical with the trachytes on Eildon Mid Hill.

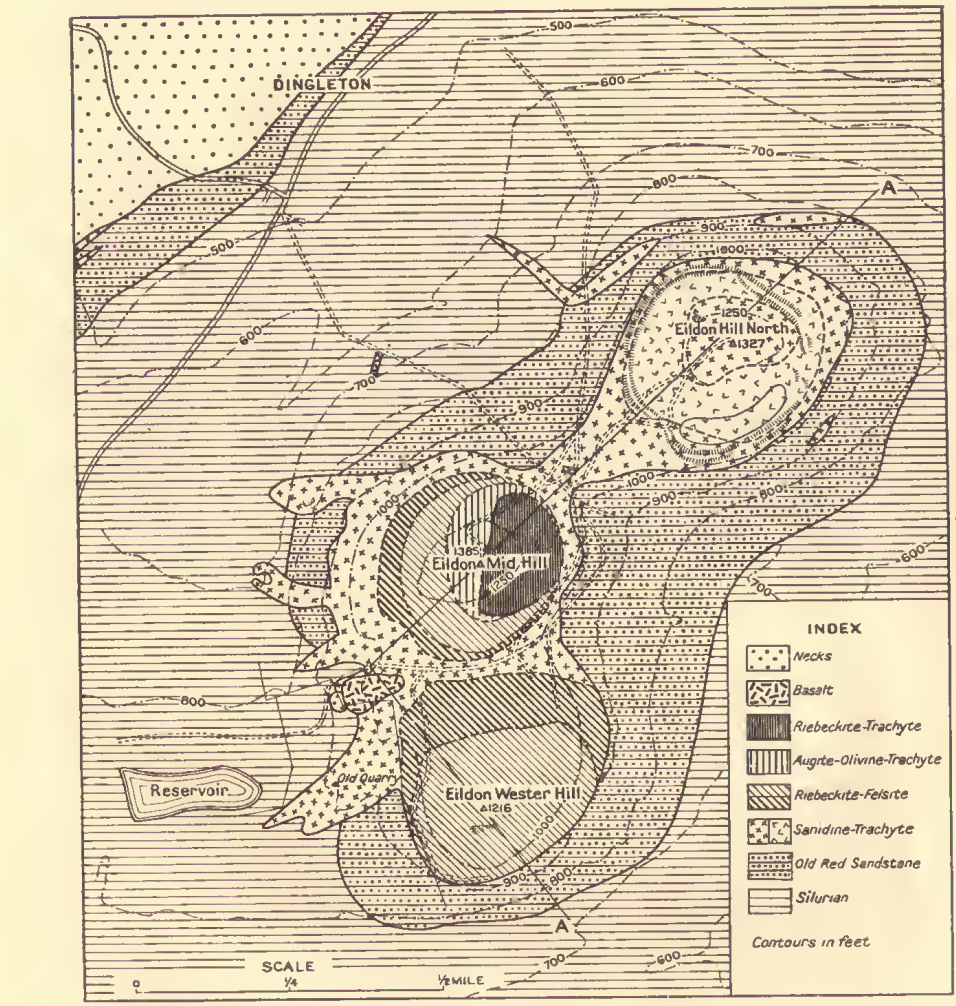

FIG. 13. *Geological map of the Eildon Hills*
(After Lady McRobert)

The neck on Greatmoor is filled by agglomerate and cut by trachyte and basaltic rocks. The agglomerate which is full of large bombs of olivine-basalt and blocks of grit and greywacke, is well exposed in a gully 90 yds. north-east of the summit. Cutting the neck is a broad dyke of olivine-basalt with large phenocrysts of olivine and augite embedded in a glassy ground-mass. Some of the olivine crystals are ½ in. in diameter, and stand out conspicuously on weathered surfaces of the rock. The dyke of trachyte forming the southern summit of the hill is a grey-green rock showing good fluxion structure. Leap Hill is similar to Greatmoor; here the tuff is cut by a dyke of Dunsapie basalt, and the two other intrusions are non-porphyritic trachytes consisting of sanidine, aegirine-augite, magnetite and olivine altered to chlorite.

There are several intrusive sheets containing nepheline or analcite; they are regarded as belonging to the same period of intrusion as the analcite dolerites in the Carboniferous Limestone Series of the Lothians. They occur at Southdean, on the watershed between Rule Water and the Liddel, and at a locality near Penielheugh north-east of Ancrum.

At Southdean the rock is a nepheline-basanite consisting of phenocrysts of augite and altered olivine lying in large plates of nepheline or an aggregate of small laths of plagioclase. According to Lady McRobert, the Penielheugh Sheet is an olivine-analcite-dolerite, and is similar to certain rocks in East Lothian.

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A. LOCH SKENE, DUMFRIESSHIRE; SHOWING CORRIE, AND MORAINIC BARRIER IN FRONT OF LOCH.

B. GLACIATED ROCKY KNOLLS NEAR FOOT OF MINNOCH WATER, KIRKCUDBRIGHTSHIRE

A. POST-GLACIAL GORGE OF RIVER TWEED AT NEIDPATH CASTLE, PEEBLES.

B. FACE OF CORRIE, BENYELLARY, MERRICK, KIRKCUDBRIGHTSHIRE.

VI. UPPER CARBONIFEROUS

THERE IS AMPLE evidence to show that the Southern Uplands along with adjacent regions in England and in Scotland were again uplifted and subjected to denudation at the close of Lower Carboniferous time. During the interval of emergence volcanoes were active in the west of Scotland, and sheets of lava were poured out over an area of low elevation during Millstone Grit time. A thin lava in the Stranraer district belongs to this period of volcanic activity (p. 74). The results produced by contemporaneous weathering are well shown by the bauxitic deposits which have originated from the extensive decomposition of the lavas. Some of the associated fireclays, containing numerous rhizomes of *Stigmaria*, obviously formed soils, and doubtless supported a dense vegetation. The movement of uplift and conversion of a large area into a land surface brought about an important stratigraphical and palaeontological break. In the interval nearly all the characteristic species of Lower Carboniferous plants and estuarine fishes had disappeared, and were later replaced by new forms when the area once more became a basin of deposition.

In the Sanquhar district the subsidence was deep enough to allow the sea to spread over the area and led to the deposition of a bed with marine fossils, but the general shallowing which followed was such as to permit the growth of plants and the accumulation of seams of coal. Intervals of estuarine conditions are marked by numerous mussel-bands. At the top of the Productive Coal Measures an invasion of the sea took place as the result of another widespread subsidence which affected all the coalfields of Britain. During this episode the well-known Skipsey's Marine Band was laid down in Scotland, and afterwards it was followed by a marked change in the fauna and flora; the formation of coal was finally brought to a close by another uplift of the region.

In the South of Scotland the 'Millstone Grit' and Coal Measures fall within the following lamellibranch zones in descending order:

Anthracoma prolifera
Anthraconauta tenuis
Anthraconauta phillipsi
Anthracomya pulchra
Carbonicola similis
Anthracomya modiolaris
Carbonicola communis

Coal Measures

1. Canonbie Coalfield

The Millstone Grit is not exposed in this area, but in the Rowanburnhead boring, where over 600 ft. of sandstones, some of which are pebbly and false-bedded, are assigned by Peach and Horne to this formation. The correlation, however, is made solely on lithological resemblance and without the support of fossil evidence.

The Coal Measures are about 3,000 ft. thick, and fall into two parts, the Productive Measures and the Barren Red Measures, as in Ayrshire. The former include the Rowanburn and Byre Burn Coal Groups, the best-known seam being the Main Coal, which is 5 ft. thick. Numerous fossil plants have been found in the associated sandstones, shales, ironstones and fireclays, and include the following forms, *Alethopteris lonchitica, Neuropteris heterophylla, Lepidodendron aculeatum, Sigillaria tessellata, Calamites undulatus, Annularia radiata,* etc.

Mussel bands are present in the lower and upper part of the Coal bearing groups, and it is probable that the Communis, Modiolaris and Similis-Pulchra Zones are represented. A shale-bed below the Archerbeck Coal, the highest worked seam, has yielded *Carbonicola aquilina, C. concinna, Anthracomya* cf. *pulchra* and other shells characteristic of the lower part of the Similis-Pulchra Zone. A marine band occurs on this horizon but its fossils are poorly preserved, and it is not possible to correlate it with one of the known marine beds in other coalfields.

The Barren Red Measures occupy a small area, and are unconformably overlain by the Trias. They consist of reddish sandstones, sandy shales and red marls, in which an occasional band of Spirorbis Limestone occurs. The beds are exposed in Liddel Water and in the Esk between Byreburnfoot and Canonbie. They contain no seams of workable coal. In Jockie's Sike, near Riddings Junction and in Liddel Water plants have been found, and include the following characteristic Radstockian species, *Asterotheca oreopteridia, Alethopteris serli, Neuropteris ovata* and *N. scheuchzeri.* Certain bands of shale in Jockie's Sike contain the shells of *Anthraconauta phillipsi,* and *A. tenuis*; these indicate a position within the Tenuis Zone. The highest beds present are believed to belong to the Prolifera Zone, a horizon which has not yet been recognized in other Scottish coalfields.

2. Thornhill

In this basin Coal Measures intervene between the Lower Carboniferous and the Permian. The most prominent member of the series is the basal grit, about 50 ft. thick. It is succeeded by sandstones containing *Calamites,* and these beds are overlain by shales and reddish fireclays. The shales have yielded poorly preserved examples of *Carbonicola* of *ovalis*-type at Drumlanrig Bridge, but these are associated with *C. concinna* and other species on a slightly higher level, and would appear to indicate a position either high in the Zone of *Carbonicola communis* or low in the succeeding Modiolaris Zone.

Still higher shales outcrop from beneath Permian sandstones in the Carron Water, near Carronbridge station, and have yielded a rich fauna of lamellibranchs, including *Anthracomya sp., Carbonicola acutella, C. aquilina, C. concinna, C.* cf. *regularis, Naiadites producta, N.* cf. *triangularis,* etc.

An important section is exposed in the Crichope Linn, two miles east of Thornhill, where grey and purple fireclays are associated with ironstones and sandy shales. The shales have yielded *Neuropteris heterophylla* and *Cordaites,* but the bands of ironstone are crowded with ' mussels,' and the following species have been recorded: *Anthracomya*?, *Carbonicola* cf. *acutella, C. aquilina, C.* cf. *concinna* and *C.* cf. *planitumida.* The abundance

of shells referred to *C. acutella* and *C. concinna* suggests that the beds occupy a low position in the Similis-Pulchra Zone. So far no seams of coal have been found. The Coal Measures, however, are largely concealed by the overlying Permian lavas and sandstones, and boring operations will be necessary to determine the presence or absence of coal in the basin.

3. Sanquhar Coalfield

A fuller development of the Upper Carboniferous rocks is met with in the Sanquhar basin. The northern boundary of the coalfield is determined by a fault, but along the southern margin Upper Carboniferous beds overlap Lower Carboniferous rocks and come to rest on highly folded Ordovician strata (Pl. IVB). The greywackes and shales below the unconformity are sometimes weathered to the depth of several feet, and it was probably from these rocks that the earliest Upper Carboniferous sediments were derived. An argillaceous matrix is typical of many of the basal sandstones, and occasionally there is a development of beds of clay which resemble the well-known Ayrshire Bauxitic Clay. The purer clays form dense rocks, breaking with a conchoidal fracture and containing veins of kaolin. The sandstones and clays have been correlated with the Millstone Grit of Scotland, and probably lie within the Zone of *Carbonicola communis*.

An important marine band (Tait's Marine Band) occurs a few feet above the bauxitic clays in the Polneul and Barr Burns, and has yielded many fossils; these include such forms as crinoid stems, *Ambocoelia urei*, *Buxtonia scabricula*, *Cleiothyridina royssi*, *Lingula mytilloides*, *Orbiculoidea nitida*, *Productus* cf. *productus*, *Schizophoria resupinata*, *Spirifer* cf. *pennystonensis* *Allorisma sulcata*, *Aviculopecten sp.*, *Palaeolima* cf. *simplex* and *Bellerophon sp.* Additional species from the Barr Burn where the fauna is less abundant are *Protoschizodus* and *Loxonema*. The Lower Carboniferous aspect of the fauna is striking, but the occurrence of *Alethopteris lonchitica*, *Neuropteris schlehani? Sigillaria elegans? S. tesselata* and species of *Calamites* and *Cordaites* places the Upper Carboniferous age of the beds beyond question. Although no freshwater mussels have been found in the lower beds, the abundance of *Carbonicola pseudorobusta* in the shales associated with the Swallow Craig Coals is taken as marking the top of the Communis Zone. These coals, which are thin and unworked, lie about 80 ft. above the marine band, and are approximately on the horizon of the Dalmellington Blackband Ironstone of Ayrshire.

The three principal coals worked at Sanquhar are the Splint, the Calmstone and the Creepie. The first named falls within the Modiolaris Zone, and is associated with mussel-bands. In the Polneul Burn, south of Nether Cairn, the roof shales have yielded numerous examples of *Carbonicola* cf. *communis*, *C.* aff. *concinna*, *C. elliptica*, *C. phrygiana*, *C.* aff. *similis* and *Naiadites* aff. *producta*. The additional species, *C.* cf. *carissima*, *Naiadites* cf. *modiolaris* and *Anthracomya modiolaris* have been found in the Catcleugh Burn in association with *Neuropteris heterophylla*, *Calamites* and other plant remains.

The boundary between the Zone of *Anthracomya modiolaris* and of the higher Similis-Pulchra Zone lies a few feet below the Daugh coal, one of the two unworked seams which occur between the Splint and the Calmstone. The Similis-Pulchra Zone is well developed, and includes all the strata

between the Daugh and a horizon a short distance above the base of the Barren Red Measures. The beds below the Calmstone contain numerous mussel-bands, but the shells are generally poorly preserved; they include *Anthracomya pulchra*, *Carbonicola acutella*, *C. concinna*, *C.* cf. *similis*, *Naiadites* cf. *carinata* and *N. quadrata*. In the strata between the Calmstone and Skipsey's Marine Band at the top of the Productive Series mussel-bands are scarce, but *Carbonicola* cf. *aquilina*, *C. regularis*, *Naiadites sp.*, *Spirorbis pusillus* and *Estheria* (*Euestheria*) *simoni* have been recorded from shales about 60 ft. above the Creepie coal. The genera *Carbonicola* and *Naiadites* disappear a short distance below Skipsey's Band. Plant remains are relatively abundant on certain levels within the zone, and the Coal Measures species characteristic of the same horizon in other coalfields are well represented.

Skipsey's Marine Band is exposed in several stream sections on the north side of the Nith, and although a thin bed it is easily located. Among the noteworthy species found in the band are *Posidoniella sulcata*, *Pterinopecten* cf. *papyraceus*, *Homoceratoides jacksoni*, *Metacoceras costatum*, *M. perelegans* and *Listracanthus wardi*, the latter being represented by short dermal spines.

The Barren Red Measures, which overlie the Productive Series, are about 700 ft. thick, and occupy the northern portion of the basin. For about 150 ft. above Skipsey's Band the measures contain red and grey bands. Above this level the sandstones and shales are of a purplish tint, and they fall wholly within the Zone of *Anthraconauta phillipsi*. The overlying Tenuis Zone is not represented. The zonal fossil, *Anthraconauta phillipsi*, along with *Estheria* (*Euestheria*) *simoni*, has been found at 180 ft. and 600 ft. above the marine band, and the associated flora includes a few Staffordian species.

The Coal Measures have been invaded by a number of doleritic sills, the largest of which is well exposed in Gateside plantation, west of Sanquhar.

4. Loch Ryan

A narrow area to the west of Loch Ryan and Stranraer is occupied by Upper Carboniferous rocks. They consist of grey, red and mottled sandstones with beds of purplish shales and fireclay, and interleaved in the series is a thin basaltic lava. The rocks are poorly exposed, but they rest unconformably on Ordovician greywackes, and are in turn overlain unconformably by Permian breccias. They have been grouped as Millstone Grit, and from shales in the Craigoch Burn the following plants have been obtained by Mr. W. Manson: *Alethopteris lonchitica*, *Calamites sp.* and *Asterophyllites equisetiformis*. From another locality near Low Knockglass, south-west of Stranraer, a thin bed of fireclay has yielded *Stigmaria ficoides*, *S. minuta* and *S. undulata*. The fireclay approximates to kaolin in composition.

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VII. PERMIAN

FOLLOWING THE ACCUMULATION of the Coal Measures, the region, probably as a whole, was uplifted and subjected to denudation before the deposition of the Permian began. The erosion that took place during the emergence, however, was variable in amount. Thus, for instance, while Permian sediments rest on rocks near the base of the Coal Measures in Loch Ryan, they are found overlying shales belonging to the Similis-Pulchra Zone, near Thornhill (p. 73), and in the Sanquhar Coalfield lavas of Permian age repose on beds of the same zone, but on a much higher position within it. Between the gently dipping Coal Measures and the Permian the unconformable relations of the two formations are not well marked, but in parts of the region where the younger set has been laid down on the highly folded Ordovician and Silurian rocks the unconformity is striking, the horizontal beds of the Permian resting on the upturned edges of the greywackes and shales.

The Permian rocks at the time of accumulation probably covered a considerable area in the south-west of the region. They are now confined to isolated basins, and owe their preservation to the fact that they occupy depressions, mostly of tectonic origin; thus they have escaped removal by denudation. They are represented by a succession of red false-bedded sandstones and bands of coarse breccia, the latter being largely made up of debris derived from the waste of pre-Carboniferous strata. The sediments resemble material that has accumulated under the action of wind on a pebbly desert; and the false-bedding which is a characteristic feature of the sandstones is of the sand-dune type; the grains of quartz forming the principal constituents of the beds are often well rounded and highly polished, and many of the pebbles included in the breccias are faceted like the majority of stones on a modern desert. At Sanquhar and Thornhill lava flows are found in the lower part of the formation, and afford evidence of volcanic activity at the commencement of the period. A Permian age is also ascribed to certain dykes and sills; these comprise theralitic essexites and monchiquites.

As a rule the sediments are unfossiliferous, but the quarries at Corncockle Muir have long been famed for the reptilian footprints found on certain bedding-planes of the sandstones. These impressions have been shown to be of Permian type, and this evidence of age is in accordance with the conclusion based on the lithological resemblance of the beds to the Penrith Sandstone of Cumberland.

The chief outliers are in Nithsdale and Annandale. In the latter district red sandstones and breccias occupy a nearly circular area north of Lochmaben. The basin is about ten miles in width, and near its centre are situated the quarries of Corncockle Muir; here, the sandstones are in places traversed by narrow veins of pyrolusite. From near Wamphray, breccias and sandstones extend northwards as a narrow band up the valley of the Annan

Water to the Devil's Beef Tub, five miles north of Moffat, where bright red sandstones are faulted against the Silurian greywackes. In Moffatdale the breccias contain fossiliferous pebbles of Carboniferous rocks. South of Lockerbie a small patch occurs in the Water of Milk.

In the Nith valley there are three separate basins occupied by Permian rocks. A tract about five miles wide runs northwards from the Solway through Dumfries to a point about six miles north of the town. The false-bedded red sandstones are largely quarried for building-stone, and are appropriately named the Dumfries Sandstones. The higher breccias are also well exposed at several localities; many of the pebbly layers are interstratified with beds of sandstone, and the fragments of greywacke and granite display faceted and angular surfaces.

Farther north Permian rocks are again found in the broad pear-shaped depression forming the Thornhill basin, where they rest unconformably on Upper Carboniferous strata. Close to the base are flows of olivine-basalt which occupy a narrow tract in the Carron Water and extend northwards almost to the mouth of the Dalveen Pass. The false-bedded sandstones were formerly extensively quarried at Gatelawbridge, near Thornhill, but the industry has now ceased. In the Sanquhar Coalfield, which forms the third basin, a small patch of olivine-basalt is present; a few small necks filled with agglomerate pierce the Coal Measures, and are regarded as being of Permian age.

About eight miles north of the Thornhill basin a patch of coarse breccias occurs in the Snar valley between the villages of Leadhills and Crawfordjohn. This outlier covers an area of about one-and-a-half square miles and occupies a depression in the Ordovician rocks. The breccia, which perhaps extended into and along the Duneaton valley, consists of angular and sub-angular fragments of greywacke and chert, obviously derived from the surrounding rocks. Some of the larger blocks are 2 ft. in diameter.

Farther to the south-west Permian rocks form a band with an average width of a mile along the western shore of Loch Ryan. They consist of red breccias with seams of sandstone, and lie unconformably on Upper Carboniferous sediments. Here, also, the pebbles of the breccias have been derived from Ordovician greywackes and cherts. Northwards from the mouth of Loch Ryan red sandstones occur as a narrow strip fringing the coast between Ballantrae and Bennane Head. At Ballantrae pier they include a breccia containing pebbles of serpentine and other rocks of the Ballantrae Igneous Series. The beds are penetrated by a mass of albite-dolerite.

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VIII. TRIASSIC

TRIASSIC ROCKS OCCUPY a smaller area than the Permian formation. They are confined to the district between Annan and Canonbie on the north side of the Solway, and lie unconformably on strata of Carboniferous age. The beds include red marls, shales, and sandstones and are in direct stratigraphical continuity with the St. Bees Sandstone of Cumberland, which is regarded as being of Bunter age.

Comparison of the Triassic sandstones with those of the Permian shows them to be lithologically distinct. They consist of sharp, angular grains of quartz and feldspar, and contain an appreciable amount of white mica. False-bedding of sand-dune type is inconspicuous or absent, and the sands appear to have been laid down in water. The marls are ripple-marked, and channels worn out in the sandstones and later filled with shale-conglomerate are the result of contemporaneous erosion. Except in the basal conglomerate no pebbles of Palaeozoic rocks have been found in the deposits. Fossils are rare, but footprints of *Labyrinthodon* have been recorded from the sandstone near Annan. It would therefore appear that the Permian deserts had become covered by sheets of water as a result of regional subsidence.

Under the term Annan Red Sandstone Series, Horne and Gregory grouped the rocks as follows: Warmanbie Sandstone, Annanlea Sandstone, Woodhouse Tower Sandstone, Robgill Marls and Allerbeck Sandstone. Recently, the Series has been investigated by Mr. B. Hilton Barrett, and he has proved that the last mentioned subdivision overlies the Robgill Marls, and is thus on the same horizon as the Woodhouse Tower Sandstone. Further, he has found that the highest beds must be referred to the Kirklinton Sandstone, and has been able to apply the classification adopted for the Carlisle Basin to the Scottish rocks.

The Annanlea Sandstone, which is a compact light red sandstone, is quarried at Corsehill, near Annan. The majority of the other sandstones have been worked at times, but the stone is soft.

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IX. TERTIARY VOLCANIC DYKES

THERE IS NO stratigraphical evidence available concerning the geological history of the Southern Uplands during the interval between the laying down of the Triassic rocks and the Glacial Period. It is generally accepted, however, that the region was buried beneath a mantle of Jurassic, Cretaceous and possibly also of Tertiary deposits, and sanction seems given to this view by a consideration of the present disposition of the river-systems of the region. The anomalous behaviour of the Nith and the Lyne and other streams is clearly explained by the assumption that the original drainage system was initiated on a platform composed of Mesozoic or later formations. The removal of the cover is a measure of the enormous denudation which the region has undergone since Tertiary times.

Basic dykes of Tertiary age, however, cross the region in a north-west to south-east direction. Of these intrusive masses perhaps one of the more important is the Eskdalemuir dyke, which appears at the southern end of the Permian basin in the Snar valley and runs by Moffat to the vicinity of Langholm. The dyke attains a width of 180 ft. in places. To the north two other broad dykes cross the boundary-fault and, entering the region north-west of Abington, extend into the heart of the Southern Uplands as far as Hartfell; indeed, the more northerly of the two is without doubt an extension of the Acklington dyke, which runs without interruption from the head of Ale Water by way of Hawick and Rothbury to the Northumberland coast. Other less striking examples occur in the Moorfoot Hills, but mention should be made of two exposures of what has been regarded as one dyke at Windy Standard, near Moniaive, and on the east of the mouth of the Nith. These intrusions are roughly in alignment with the Caponcraig dyke of the Ayrshire coalfield and the Cleveland dyke south of Carlisle. In the Girvan area narrow dykes probably of the same age cut the Silurian rocks exposed on the beach between Woodland Bay and Ardwell Farm, and the Arenig volcanic series south of Kennedy's Pass.

The dyke-rocks are mainly tholeiitic quartz-dolerites and are undoubtedly members of the Mull Swarm.

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X. GLACIAL AND SUPERFICIAL DEPOSITS

THE ONCOMING OF glacial conditions was probably accompanied by the development of local glaciers, but all traces of their erosive action have been obliterated by movements of later sheets of ice. At the period of maximum glaciation the Southern Uplands were completely buried beneath a mass of moving ice, which, as is evident from the direction of striae and trails of erratic blocks, moved from several distinct centres outwards and downwards into the lower ground (Fig. 14). Thus, west of Nithsdale the elevated region of Merrick, Rinns of Kells and Cairnsmore of Carsphairn formed an axis along which the ice-sheet divided. The ice streaming northwards towards the Ayrshire plain impinged on the Highland sheet, which had reached the Midland Valley, and was then deflected partly to the east and partly to the south-west; the latter, on meeting the stream of ice moving down the Firth of Clyde, changed direction and travelled southwards over the Mull of Galloway. On the southern side of the axial region the ice-sheet moved south, and on reaching the Solway it divided against the *mer de glace* occupying the Firth; one part turning towards the south-east moved off into England, the other portion joining the ice travelling down the Irish Channel.

Another dispersal-centre occupied the high ground at the headwaters of the Ettrick, the Yarrow and the Tweed. From this axis the ice-sheet moved off towards the north-east, and then turned to the south-east over the broad Merse of Berwickshire into Northumberland, where it joined the Solway ice. Along the northern margin of the Uplands ice travelled from west to east and, as the presence of boulders of kylite indicates, some of it entered the Nith and occupied the valley to beyond Sanquhar; but the main sheet streamed along the Midland Valley and turning towards the south moved over part of the Lammermuirs along with ice having its source in the Highlands. The southerly deflection of this sheet was brought about by the pressure exerted by the Scandinavian *mer de glace* occupying the North Sea.

It is probable that immediately prior to the advent of the Ice Age the main features of the drainage system differed but little from those of the present day; consequently, it is in the valleys that thick accumulations of boulder clay are found. This deposit is a stiff, unstratified clay full of subangular stones, and varies in composition and often in colour according to the nature of the underlying strata, but it frequently contains rocks which have been carried from distant localities. The boulders lie in all positions, and the majority of them are scratched, grooved and even roughly polished. In the south-western part of the Southern Uplands, particularly in Galloway, the deposit shows a tendency to be arranged in parallel mounds or drumlins. The long axes of these mounds coincide with the direction of the ice-flow, and indicate that arrangement had taken place under the glacier. In Peeblesshire and Selkirkshire the boulder-clay is usually thicker on the west side of the valleys than on the east, a result due to the movement of ice from west to east. Between Bennane Head and

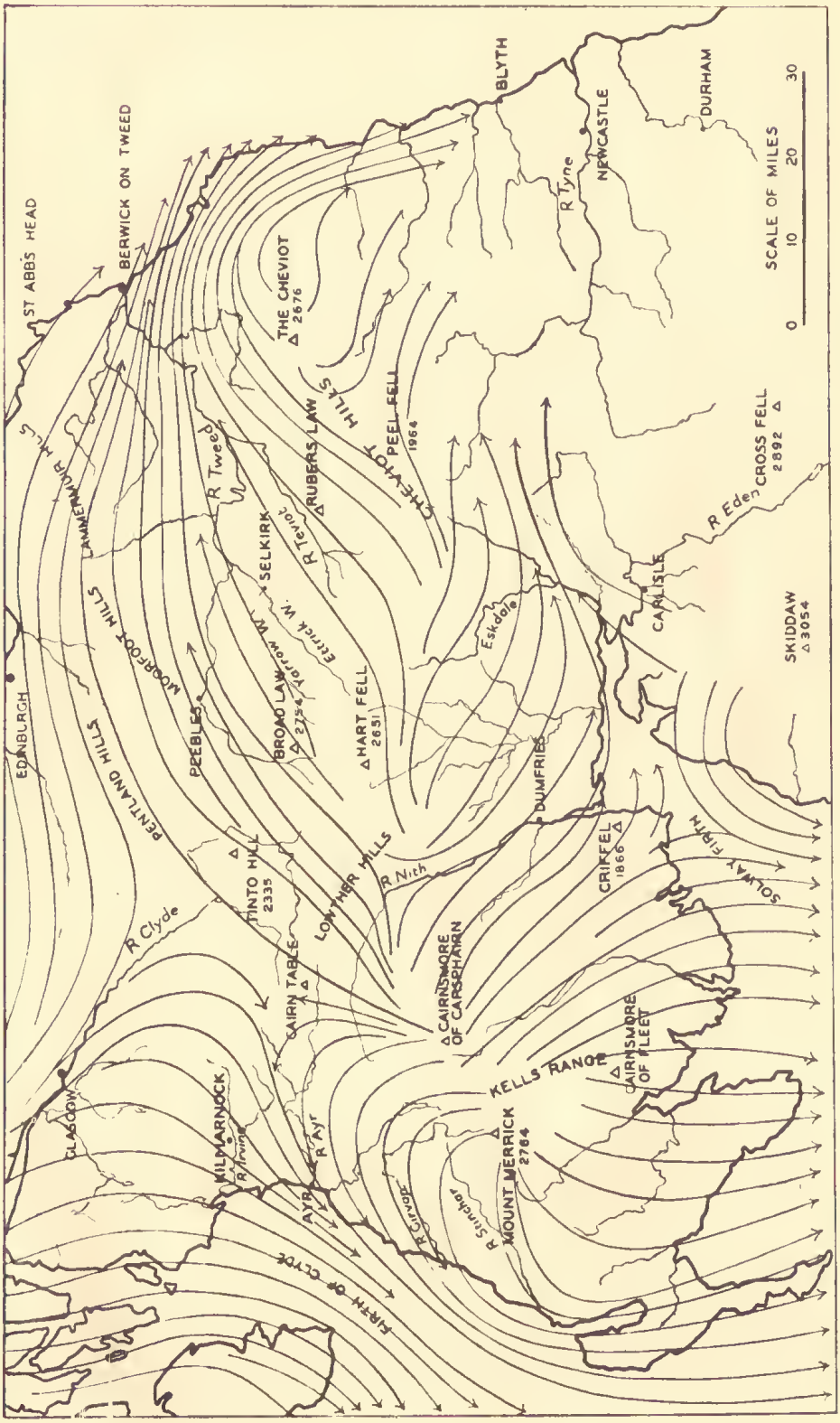

FIG. 14. *Map showing direction of ice movement in the South of Scotland*

Ballantrae and along the coast of Clanyard Bay and Port Logan in the Rinns of Galloway, the boulder-clay contains fragments of marine shells, and evidently represents an invasion of ice which had moved along a part of the Firth of Clyde.

As a result of amelioration of the climate, ridges of the higher portion of the area appeared as nunataks, and marked the establishment of valley glaciers. Their movements were determined by the seasonal falls of snow; hence they show stages indicating retreat and advance. The retreat of the ice is marked by a succession of moraines, which rest either on bare glaciated rock surfaces or on boulder clay. These morainic deposits, which consist mainly of sand, gravel and erratics, are usually current-bedded, and form long winding ridges. They are obviously made up of material carried on or within the ice, and thus differ from boulder clay. Examples of moraines are found in many parts of the region, but mention should be made of the remarkable display between Greenlaw and Duns in the lower part of the Tweed valley and in the Midlaw Burn, near Loch Skene, in Dumfriesshire (Pl. VA). Charlesworth has described five stages of retreat in the Cree valley; these he has termed the Monreith, Kirkcowan, Newton Stewart, Minnoch and Corrie Stages, each named after the locality at which the best development is found. A typical corrie is shown on Pl. VIB. Frequently, as at Neidpath in Peeblesshire, the morainic deposits are associated with beds of silt and ' gutta-percha ' clays which had accumulated in lakes in front of the ice during a temporary retreat, and were later covered by sand and gravel during a re-advance of the ice.

The final retreat of the ice is marked in this region as elsewhere by a spread of fluvio-glacial gravels and sands. These deposits were laid down around masses of ' dead ' ice and, after the ice had melted, the hollows were filled with sheets of water (kettle-holes, etc.). Many of these lakes have disappeared in the course of time and their sites are now indicated by tracts of lacustrine marls or alluvium; good examples are still to be seen at the Todholes, near Selkirk, and other parts of the Border country. In the south-west there are scores of small lakes, some of which occupy rock-basins (*see below*) between Merrick and Luce Bay. Overflow channels are numerous in various parts of the region. Several of these have been described from Peeblesshire, and their occurrence in other districts is well known. They occur at various levels. An interesting example of a high-level channel may be seen near the junction of the Ettrick and the Yarrow. In this instance the overflow was perhaps caused by ' dead ' ice in the Ettrick damming back the water in the Yarrow until it rose to a height where escape was possible.

Numerous examples of temporary or permanent divergence of drainage may be noted on Tweedside and elsewhere, and since Glacial time some of the most picturesque gorges in the region have been eroded by rivers diverted from their former courses (Pl. VIA), while their older valleys remain filled up with boulder clay. One of these diversions may be seen between the river Jed and Oxnam Water, near Jedburgh.

Rock-basins. The passage of ice over the region is also reflected by ridges and hollows formed by the erosive action of ice on the rocky floor (Pl. VB). In the south-west many of the lochans occupy ice-worn basins in the Merrick district, but the more important examples are Loch Doon, St. Mary's Loch and Loch Trool (Pl. IIB). Loch Skene, in Dumfriesshire,

is perhaps another rock-basin but largely owes its existence to moraines left by Corrie glaciers. These deposits, which originally impounded the waters of the loch, have since been breached by the Tail Burn. This stream a little lower in its course cascades over a rock-wall about 300 ft. high on its way to join Moffat Water. The waterfall, known as the Grey Mare's Tail, forms one of the most striking examples of a ' hanging valley ' in the South of Scotland.

Raised Beaches. With the exception of the area east of Dunbar, there are no raised beaches on the north-eastern sea-board of the region, where the cliffs of folded Silurian rocks rise abruptly above the sea. Between Dunbar and Linkhead, however, the 25-ft. raised beach extends almost continuously, but beyond the latter place only patches of the beach are seen as far east as Reed Point, near Cockburnspath.

Along the south-west coast and the shore of the Solway Firth there is abundant evidence of the change of the relative position of land and sea. Between Girvan and Ballantrae the 25- and 50-ft. beaches form a marked feature along the coast. Farther south, in the broad belt of low-lying ground between Loch Ryan and Luce Bay, there is a succession of broad terraces which fringe the coast almost to the Mull of Galloway. Here the 25-ft. beach consists of gravel, shingle and sand with numerous remains of recent littoral shells. The higher terraces at 50 ft., 75 ft. and 90 to 95 ft. are less well defined, and are composed of gravel and sand devoid of organic remains. On various parts of the Solway coastline the 25-ft. beach is conspicuous. In the broad, low-lying tract between Newton Stewart and Wigtown, and at the mouth of the Urr Water, there are three terraces at 25 ft., 50 ft. and 100 ft. respectively. The deposits consist of sands, gravels and laminated clays. Again, on the east and west banks of the Nith the 25-ft. beach is a prominent feature and fringes the coast for many miles.

Caves. Changes of level are also indicated by various sea-worn caves on parts of the south-western coast, at Bennane Head, near Ballantrae, and along the Solway Firth. Of these the most important is the Borness Cave, Kirkcudbright, which has yielded abundant remains indicating occupation by man. The floor of the cave is about 19 ft. above high-tide level, and its erosion by the sea probably belongs to the time of the 25-ft. beach. The objects found include bones, burnt wood, shells, grain, implements of bone and stone and bronze ornaments of Romano-British age.

River Terraces. Most of the rivers are bordered by a succession of gravel terraces marking the gradual deepening of their channels. It is probable that they bear a similar relation to former sea-levels as is indicated by raised beaches. Thus, in the lower reaches of the Tweed the terraces that rise to heights of 60 to 80 ft. above the river appear to correspond to the 100-ft. raised beach, while those that occur 30 to 40 ft. lower are probably of the same age as the 50-ft. beach; the terraces at still lower levels may be equivalent to the 25-ft. beach.

Peat. Much of the higher ground of the Southern Uplands is occupied by large tracts of peat, which may attain a thickness of nearly 20 ft. In the districts of Merrick, Kells and Tweedsmuir the peat-mosses rest on moraine-material; that some of the peat had accumulated during cold periods is indicated by the occurrence of an Arctic plant bed between the lower and upland wood beds. The decay of the hill peat may be seen in many parts of

the region, and the black broken edges of the peat hanging down the heather-clad slopes are a characteristic feature of the landscape in parts of the Cheviots and many of the high hills between the Moorfoots and the elevated region around Merrick.

On the lower ground there are large peat-mosses between Glenluce and Kirkcowan, at Kirkconnel, near Dumfries, and the Solway Moss; but those in the counties of Peebles, Selkirk, Roxburgh and Berwick are of no great extent. They are largely composed of birch, and no Arctic plants have been recorded from them. Traces of a submerged forest in Dumfriesshire are found at Islesteps and at the mouth of New Abbey Burn. In a deposit of peat exposed at low tide in Bridgehouse Bay, Kirkcudbright, a pair of antlers of the red deer was unearthed many years ago.

Blown Sand and Alluvium. Except in the south-western parts of Wigtownshire, there are few accumulations of blown sand; at the head of the Bay of Luce, however, sand forms hillocks and ridges covered with coarse bent.

Deposits of river alluvium fringe most of the rivers, and in the valley of the Tweed and its tributaries, particularly in the lower part of the Tweed, they form the broad plains known as haughs. The sites of lakes, which have disappeared, are invariably indicated by patches of lacustrine deposits. Marine alluvium is of trifling extent, and is confined to certain parts of the Solway Firth.

Man. Flint implements of Tardenoisian age are numerous at the head of Luce Bay, near Stoneykirk. There is also evidence that early neolithic man of the same culture made his way into the heart of the Southern Uplands. One locality which lies 80 ft. above the river near the junction of the Tweed and the Ettrick has yielded thousands of flint-flakes, cores, scrapers and other implements. The abundance of flint-chips suggests that the site formed a chipping-floor. In the absence of flint, either in the rocks or in the superficial deposits of the district, it must be concluded that the unworked material was imported by man from some distant locality.

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XI. ECONOMIC PRODUCTS OF THE SOUTH OF SCOTLAND

THE REGION IS largely devoted to sheep-rearing, and agricultural pursuits are confined to the broad haughs that floor the valleys. In the lower reaches of the Tweed and Teviot, particularly in the Merse of Berwickshire, crop-raising is carried out on a fairly large scale.

Building Stone. The Ordovician and Silurian rocks provide several varieties of durable building stone, and many of the towns and villages, especially those in the Central Belt, are built of greywackes and grits obtained from the Llandovery formation. These and certain intrusive rocks have been largely used in the construction of stone fences or quarried for road-metal. Some prominent bands of shales have been worked at Stobo, Grieston, Thornilee and other localities and used as slates.

In Teviotdale some of the sandstones of the Upper Old Red Sandstone and the higher Carboniferous have been used for building purposes, but in Dumfriesshire the red Permian and Triassic rocks are employed in preference to the greywackes. The Carham stone which is found close to the base of the Carboniferous has long been worked at Carham, Haddon and Sprouston in Berwickshire.

For the construction of docks and for ornamental purposes the granite intrusions have been extensively quarried at Dalbeattie and Creetown. Some of the varieties of serpentine and porphyritic lavas in the Ballantrae district deserve attention as a source of material for ornamental uses.

Limestone. The Ordovician limestones of the Girvan area are still used for the manufacture of lime for agricultural purposes, but the majority of the quarries in the Craighead and other limestones near Girvan and in Peeblesshire have been abandoned. The limestones of Carboniferous age were formerly worked on a big scale at Thorlieshope in Liddesdale and at Closeburn and Barjarg, near Thornhill.

Lead Ore. Galena has been mined at Leadhills, Wanlockhead, Blackcraig, near Newton Stewart and at Carsphairn. Mining operations were in progress at Leadhills and Wanlockhead up to 1939 and 1934 respectively. Here the ore occurs in veins in Ordovician rocks. A peculiarity of the district is the gradual disappearance of metalliferous conditions as black shales are approached either horizontally or vertically. The trend of the veins is from west-north-west to east-south-east, and they hade towards the east at 70°–75°. The galena is associated with zinc-blende, quartz and calcite. The lead formerly worked at Blackcraig occurred in veins traversing Llandovery strata.

Iron. Narrow veins of haematite are found in Ordovician and Silurian rocks at various localities. The ore occurs in association with galena at Leadhills and Wanlockhead; but with the exception of a prominent lode in the Coran of Portmark, near the eastern margin of the Loch Doon granite, it does not appear to have been worked to any extent. Traces of chalybite occur in a vein at Tonderghie, near Whithorn, Wigtownshire, in association

with copper. In the Upper Old Red Sandstone the occurrence of haematite has been recorded at Riccarton.

Copper. Veins of carbonate of copper traverse grits and shales below the junction of the Whiteadder and Dye Water in the Lammermuir Hills, and the same ore is associated with barytes in the Priestlaw granite mass where both minerals have been worked to a small extent. Copper pyrites is occasionally found in the Leadhills, and a narrow lode of the same ore was formerly mined at Wauk Mill, near Kirkcowan, in Wigtownshire.

Antimony. Small quantities of antimony are met with in the Leadhills; it has also been mined on part of the Knipe granite mass, south-west of New Cumnock, in Glenshama Burn in Dumfriesshire, and in Meggat Water, near Langholm.

Manganese. Small quantities of pyrolusite have been found in the Leadhills, and narrow veins of the mineral traverse the Permian sandstones of Corncockle Muir.

Zinc. Sulphide of zinc (Black Jack) frequently occurs in association with galena at Leadhills, Wanlockhead and Blackcraig, near Newton Stewart.

Mispickel. Arsenical pyrites has been noted in a vein along the junction of the Cairnsmore of Fleet granite with the greywackes in the valley of Palnure, north-east of Newton Stewart. Close to the edge of the same intrusion a nickeliferous ore has been found at Talnotry.

Silver. This mineral has been extracted from the galena veins of Leadhills, Wanlockhead and Blackcraig.

Gold. Small quantities have been obtained from the alluvial deposits of streams in the Leadhills and in Glengaber Burn, near St. Mary's Loch, in Selkirkshire.

Barytes. Veins of barytes occur in the district of Auchencairn, near Barlocco, Kirkcudbrightshire, where the mineral was formerly worked. Its occurrence in association with copper pyrites in the Lammermuir Hills has been referred to above.

Coal. The principal seams of coal worked in the Southern Uplands are those mined in the Sanquhar Coalfield (*see* p. 73). In the Canonbie Coalfield there are at least eight coals of workable thickness in the Productive Measures, but the pits are now closed. Certain of the thin coals in Liddesdale have been used locally for fuel.

Mineral Wells. Sulphurous springs occur at Moffat, Kirkurd in Peeblesshire, and Lawriestone, near Castle Douglas. The well at Moffat at one time attained considerable popularity. Chalybeate springs are found near the outcrop of pyritous shales at many localities. The most famous of these is St. Ronan's Well, Innerleithen.

Water Supply. Few regions are more favoured than the South of Scotland in having copious supplies of excellent water for drinking purposes. Most of the water is obtained from springs, and the city of Edinburgh has a large reservoir at Talla, near Tweedsmuir. Large quantities of water are pumped from the Permian sandstones and breccias for use at the Royal Crichton

hospital and a number of private houses in Dumfries. Should occasion arise it is highly probable that the same formation occupying the basin north of Lochmaben would yield supplies of water ample to meet the needs of the district.

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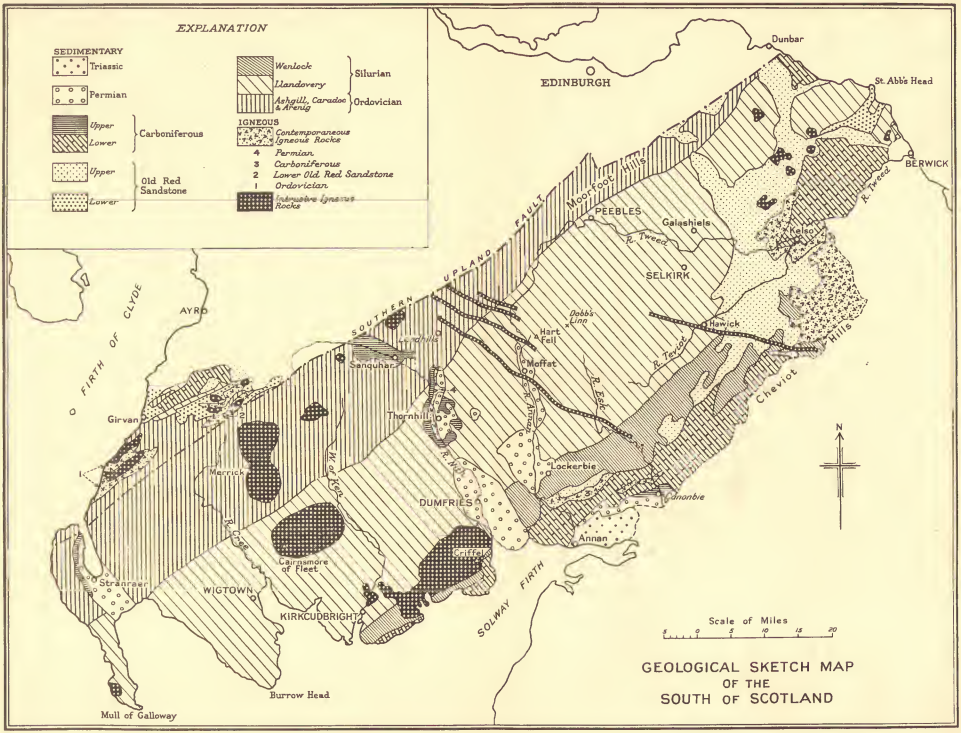
EXPLANATION
SEDIMENTARY
Triassic
Permian
Upper
Lower
Carboniferous
Upper
Lower
Old Red Sandstone
Wenlock
Llandovery
Silurian
Ashgill, Caradoc & Arenig
Ordovician
IGNEOUS
Contemporaneous Igneous Rocks
4 Permian.
3 Carboniferous.
2 Lower Old Red Sandstone
1 Ordovician.
Intrusive Igneous Rocks
EDINBURGH
Dunbar
St. Abbs Head
BERWICK
R. Tweed
Moorfoot Hills
PEEBLES
Galashiels
Kelso
R. Tweed
SELKIRK
Hawick
Dobb's Linn
Hart Fell
Moffat
R. Teviot
Cheviot Hills
SOUTHERN UPLAND FAULT
Tarfside
Sanquhar
R. Esk
Thornhill
Lockerbie
Ecclefechan
Annandale
DUMFRIES
Annan
Criffel
SOLWAY FIRTH
Merrick
R. Dee
R. Cree
Newton Stewart
Cairnsmore of Fleet
Stranraer
WIGTOWN
KIRKCUDBRIGHT
Burrow Head
Mull of Galloway
AYR
FIRTH OF CLYDE
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